AFIT/GLM/LSY/93S-4

RESEARCH AND DEVELOPMENT PROJECT SELECTION TOOLS:
PROBING WRIGHT LABORATORY'S PROJECT SELECTION
METHODS AND DECISION CRITERIA USING THE
LATERAL AIRFOIL CONCEPT

THESIS

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THESIS

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Finally, I thank God from whom all blessings flow.

James E. Barger

Table of Contents

Page

Page

List of Figures

Page

List of Tables

Abstract

This research accomplished three major tasks. First it examined familiarity and usage rates for fifteen published R&D project selection methods in the context of a larger general issue, the Air Force's ability to develop and exploit technology. Wright Laboratory served as the focus for the research effort and displayed a greater tendency to use formal methods in 1993 than was shown in prior research. The study identified an adaptive organization exercising different techniques through the years, across structure, and down hierarchical levels to meet unique decision environments. An overall preference for simpler models like Checklist, Scoring, and Sorting models led to a recommendation that authors familiar with the other techniques communicate them in engineering and management vernacular.

Secondly, the study introduced a technological paradigm, lateral airfoils. A bibliometric search for patent designs dating to 1910 suggested a sustained trend in the technology's art and application. The methodology employed one of three new lateral airfoil applications introduced in the narrative to meet the third initiative.

Finally, the study uses a "placebo" lateral airfoil research project to gauge Wright Laboratory's decision making process. The study revealed thirty discrete criteria and successfully reduced these to seven determinant attributes indicative of overall laboratory support for applied science research efforts.

RESEARCH AND DEVELOPMENT PROJECT SELECTION TOOLS: PROBING WRIGHT LABORATORY'S PROJECT SELECTION METHODS AND DECISION CRITERIA USING THE LATERAL AIRFOIL CONCEPT

I. Introduction

1.1 Introduction to the Chapter

This chapter introduces the investigation topic by describing the general and specific issues, research objectives, research questions, scope, limitations and assumptions. A summary of the information appears at the end of the chapter.

1.2 General Issue

The government of the United States of America's government funds many types of research. The nation's investments in knowledge, people, educational pipelines, facilities, and equipment provide extraordinary benefits. American science and technology are a testament to the nation's greatness.

Our national pursuit of scientific research advances at a phenomenal rate on two fronts simultaneously. These fronts are commonly called basic and applied research. The aim of basic research is discovery of the unknown that is accomplished by scientists who explore the mysteries of their discipline. Applied research works hand-in-hand with basic research, focusing on problems in using fundamental concepts, theories, methods, or findings.

Throughout the 1960's and early 1970's the United States Department of Defense (DoD) supplied the largest single source of basic and applied research funding (OTA, 1991:8). DoD funding levels routinely exceeded National Science Foundation (NSF) levels by a factor of at least two to one. Today, DoD's spending level is far less than the National Institute of Health (NIH), who serves in the lead "funding agency" role. Yet, America's military agencies still dispense nearly $3 billion annually for research and development (R&D) (OTA, 1991:102). The DoD distributes funds for basic and applied research through the Army, Navy, Air Force, Defense Advanced Research Projects Agency of 1992 (DARPA) or Advanced Research Projects Agency of 1993 (ARPA), and Strategic Defense Initiative Organization of 1992 (SDIO). It routinely categorizes R&D funding into three categories: 6.1 - fundamental research or basic research; 6.2 - applied research and exploratory development; and 6.3A - the initial stages of advanced development.

DoD and the national scientific community as a whole have tremendous research capability, yet there are more basic and applied research opportunities than the country can resource. The Office of Technology Assessment (OTA) suggests that "The objective, then, is to ensure that the best research continues to be funded" (OTA, 1991:7).

> ***OTA finds that under almost any plausible scenario for the level of research funding in the 1990s, there are issues of planning, management, and progress toward national goals to address. (OTA, 1991:10)***

The difficult task becomes reducing the list of potentially fruitful opportunities, finding the "best" research for funding. Aviation Week & Space Technology highlighted one segment of government facing this issue, reporting, "Proposals for the Advanced Research Projects Agency's Technology Reinvestiment Project far outstrip its ability to fund them" (Lavitt, 1993:17).

How will the nation effectively allocate its R&D resources? How can federal, state and local government, academia, and industry set priorities? These questions are as hard to answer as they are easy to understand. The fluid political environment characterized by changing funding patterns and increasing pressures, both internal and external to the national research system, promises a complicated future and demands a coherent policy.

> ***OTA finds that Congress, the executive branch, and research performers must converge on these issues. Potential congressional actions fall into three categories. Congress can: 1) retain primary responsibility for decisions and initiating actions; 2) place some of the responsibility for coordination and decisions on the executive branch; and 3) encourage research performers (especially universities, as well as Federal and industrial laboratories) to address components of this issue. (OTA, 1991:43)***

This thesis meets OTA's challenge of encouraging research performers to address components of national need by delivering information on how Wright Laboratory selects research projects. Further, the research partially alleviates a separate situation identified by OTA where ". . . most analysis and research decision making must draw conclusions from the NSF and NIH data system" (OTA, 1991:233).

The discussion that follows addresses the general issue briefly introduced in the preceding paragraphs. It uses four factors: Air Force Doctrine, budget, mismanagement, and indigent factors.

1.2.a Air Force Doctrine. The forward of Air Force Manual 1-1, *Basic Aerospace Doctrine of the United States Air Force,* asserts that the text is "one of the most important documents ever published by the United States Air

Force" (AFM1-1, 1992:v). This statement by the Chief of Staff underscores the manuscript's importance and signals its potential for framing present and future Air Force policy. Chapter four of AFM 1-1 advocates that the "Air Force should be in the forefront of developing and exploiting aerospace power" (AFM1-1, 1992:17). This position springs from a wealth of historical precedents that chronicles research and development efforts, and the effects of technology's exploitation. Traditionally, these elements have been recognized as the driving force that propelled the Air Force to the forefront of global aerospace power. Various textbooks devoted to subjects unrelated to war or aerospace doctrine also acknowledges technology's significance. Consider the following quotation from an Economics text:

> ***Whether a firm produces textiles or locomotives, whether a firm is big or small, whether a firm is run by a genius or a moron (or even your brother-in-law), the firm cannot do more than is permitted by existing technology. (Mansfield, 1991:142)***

Technology is a limiting factor in commercial business and war, notwithstanding the argument that war is a business. Yet, recent national trends threaten the Air Force's ability to push technology's leading edge.

> ***Sometimes the advantage of a superior weapon is decisive before countermeasures can be evolved. It follows then that the methods used to select and develop new weapons and the doctrines concerning their use will have an important bearing upon the success or failure of Armies - and of nations. (Holley, 1953:5-6)***

This thesis' general issue centers on the Air Force's ability to develop and exploit technology. R&D project selection methodologies and criteria employed for resource allocation receive particular emphasis.

<u>1.2.b The Budget Factor.</u> The current United States economic condition moderated by the perceived post-Cold War stability is forcing law makers to make tough monetary decisions. Intense budget discussions prompted by fiscal expenditure constraints initiated in the early 1990's may yield lasting effects. However,

> ***The combination of the most obdurate economic recession since the 1930s, the severe limits the White House and Congress imposed on discretionary spending and the inability to staunch the flow of red ink now suggest that a budget debacle is imminent.***
>
> ***(Goodwin, 1992:55)***

Throughout 1992 and early 1993, many senior military leaders and their civilian counterparts suggested a high potential for military monetary reductions. Many lawmakers pledged their support of efforts to pare down the Pentagon budget to get a 'Peace Dividend' (Goodwin, 1992:57).

> ***With the end of the Cold War, many people look to the defense budget for a peace dividend --that is, for funds that can be redirected to other purposes including domestic programs, tax cuts, and deficit reduction. (CBO, 1992:61)***

Major General Smith, Chief of Staff for Logistics, United States Air Force Material Command suggested in 1992 that the Air Force could expect reductions greater than or, at best, equal to 25 percent in this environment (Smith, 1992). Large segments of the Air Force, including its Research and Development (R&D) organizations and extended civilian contracting community, will experience the repercussions from down-sizing actions of this magnitude. Initially, the R&D community's reaction included 'zero-sum' budgeting, where new projects are offset by cuts in older projects while maintaining a certain level of fiscal expenditure. Dr Allan Bromley, the President's science advisor, extolled this position during the twilight of President Bush's administration (Goodwin, 1992:57).

As the competition for money escalates throughout the 1990's, creative reactions may emerge. Intense competition for scarce budgetary funding surfaced in the R&D community as early as December 7, 1992 when *Aviation Week & Space Technology* published its cover story titled, "U.S. Labs Reorient to New Endeavors." The following article excerpt records the laboratories' public announcement of refocusing efforts in the wake of a new world order.

> ***The US Government's network of defense-related laboratories is adjusting to the post-Cold War world in much the same way as the aerospace industry. The labs are focused on an aggressive search for new financial alliances . . . (Fulghum, 1992:46)***

A follow-up article published as part of a Global Aerospace/Defense Industry 5 Year Outlook reaffirmed initial refocusing activities.

> ***Defense R&D will not be short-changed over the next five years, but will undergo drastic restructuring. Energy Dept. laboratories will be challenged to find industrial partners to share development costs and revenues or go out of business. However, as they seek closer ties with industry, the labs' risk losing some of their best scientists and engineers to higher paying commercial partners. Competition among laboratories will be a way of life as they scramble for both military and commercial funds. (Scott, 1993:59)***

Inevitability, military R&D projects and portfolio's may face reductions in scope, extensions in project lead times, and possible elimination. Unfortunately, these actions will negatively affect many potentially fruitful research technologies. A *Business Week* journalist writes:

> ***For the first time in years, a broad array of science projects - from the space station to efforts to boost commercial technology could be vulnerable to budget-cutters on Capitol Hill. (Carey, 1992:66)***

Even relatively small Air Force projects will undoubtably come under the same scrutiny. This, then, poses a dilemma for senior decision makers who function under Air Force guidance. On which vision do they focus? Should a decision maker place equal importance on more than one goal? How does a decision maker ensure the Air Force remains in the forefront of aerospace technology while there are other competing goals, like staying within a budget?

Although, the Air Forces' basic aerospace doctrine recognizes a fluid environment, R&D monetary reductions ultimately make the dynamic technology exploration passé while exacerbating tradeoffs, "such as those between mass and flexibility, functional excellence and versatility, and predictability and adaptability" (AFM 1-1, 1992:225).

1.2.c The Mismanagement Factor. Increasingly, media's attention has focused on R&D mismanagement. The broad spectrum of personality types and large sums of money, $43.3 billion in R&D for fiscal year 1993 (FY93) (Goodwin, 1992:57), makes R&D a "target rich" environment for mismanagement. In its most disgracefully corrupt form, the mismanagement cry accompanies public scandal.

> ***. . . scandals over the misuse of federal research dollars at Universities such as Stanford and allegations of misconduct in prominent labs have hurt science's image.***
> ***(Carey, 1992:68)***

Do senior corporate executives perceive mismanagement in peacetime in the same light as mismanagement on the battlefield? Hughes Aircraft Company's Chairman and Chief Executive Officer notes that,

> ***Peace in our time creates a new world order with complexities and dangers of its own. Unless we understand the peace and learn to survive in it, we as a nation can lose even more in terms of our vitality and standards of living as from defeat in an actual shooting war. (Currie, 1991:50)***

Whispers of mismanagement often bubble to the surface in subtle forms, shrouded in funding debates. Consider the following excerpt that discusses a seemingly 'quality based' decision.

> *. . . drug companies have been scaling back research on antibiotics and other antimicrobials and turning instead to anticancer and antiviral drugs. So when drug-resistant TB first came to national attention in 1991, there was no U.S. source for two TB drugs that were formerly used to treat the disease . . . Thomas L. Copmann, head of the bio-technology of the Pharmaceutical Manufacturers Association, places the blame on the 'dismal' amount being spent on drug resistance by the National Institute of Health. (Beardsley, 1992:20)*

While the writer may be advocating the need for higher funding levels, one could also imply a criticism for mismanagement of current funding levels. Strong, quality management tools and methodologies serve as the best protection against the mismanagement stigma. Primarily, an appropriate array of these elements enables superior R&D portfolio decisions and minimize opportunities for criticism. However, if questions do arise, they function as the bulwark in the debate over how to "get the most bang for the buck!"

1.2.d The USAF Indigent Factor. R&D decision makers need an assortment of tools to discriminate between research projects. The typical USAF R&D Manager retains responsibility for evaluating project research potential, comparing project feasibility, selecting appropriate research technologies, and securing or distributing research funding. Past Air Force sponsored research revealed that decision makers relied on "intuition and expert judgment" as the primary means for project selection (Congdon, 1988:69). Other studies have confirmed this observation as DOD standard practice (Robinson, 1991:576). Additionally, the USAF has followed the governmental scientific research community as a whole by not adopting or publishing decision making criteria for research project discrimination.

> ***Although both D. Allan Bromley, President Bush's science adviser, and Frank Press, president of the National Academy of Sciences, have identified criteria and types of priorities that they consider essential for science, neither addresses the problem that there is few mechanisms for, and no tradition of, ranking research topics across various fields and subfields of inquiry. In addition, priority setting is often resisted by recipients of federal funds who fear the loss of support for their particular speciality.***
> ***(Chubin & Robinson, 1991:B2)***

However, a caution is in order. This type of public criticism does not prove gross error or negligence. In fact, it highlights a range of problems encountered by ranking research topics identically across subfields of inquiry. The following paragraphs animate three views in the debate.

First, consider the case of a large research facility like Wright laboratory. The organizational structure for overseeing three thousand people requires a hierarchy with laboratory, directorate, branch, and section tiers. Should decision makers use the same methods or criteria at all organizational levels? Do decision makers need to compare research projects at the laboratory or aggregate level using the same determinant attributes that have been used for ratings at discrete, lower levels? These questions echo of the proverbial comparison of apples to oranges. A comparison usually avoided at all costs, but, which may be okay in special cases.

For example, assume a grocery store manager and homemaker are interested in quality. When the manager performs a quality inspection, it makes little difference if the object is an apple or an orange. The manager's only interest is in the quality of the fruit. However, a homemaker who is interested in apples and oranges, proceeds under a different agenda, (i.e. is the apple a high quality Winesap or a poor quality Johnathan apple?). In other words, the store manager's determinant attributes for quality may have little to do with the homemaker's determinant attributes for quality. Bringing this example back to the R&D debate, one can see that the laboratory's criteria for a portfolio candidate may differ substantially from any discrete branch's criteria for an R&D proposal.

Secondly, identical decision making criteria may not universally apply between laboratories and directorates. For example, Wright Laboratory's Materials Directorate may use its own distinctive set of determinant attributes while the Propulsion Directorate may use another set. It's not that one directorate labels its sister directorates' criteria as unimportant; it's simply that their criteria may not apply. Trying to force a particular criteria's usage across a laboratory's directorates may present a continuum of problems ranging from inconvenience at the branch or division level to impracticability at the laboratory decision making level. Therefore, a laboratory management's enforcement efforts for exactly the same decision making criteria may simply be fruitless.

Thirdly, a fair introduction of the topic as it relates to the Air Force arena requires a discussion of past practices. Prior Air Force graduate research studies on this issue document that both projects and portfolios are compared. However, the lack of any comparison method would come as no surprise, since surveys at both military and civilian institutions document R&D decision makers' reluctance to adopt systematic project assessment methodologies (Liberatore, Titus, 1983:962; Prince, 1985:40; Congdon, 1988:73-4). The research of Prince (Prince, 1985) and Congdon (Congdon, 1988) firmly communicate that R&D comparisons are indeed made at many bureaucratic levels within Wright Laboratory at Dayton, OH. However, their research also suggests that the methodologies and determinant attributes may vary between directorates.

After reviewing the three tenets presented above, it should be apparent that there are many reasons why differences in methodologies exist and why standards for research project comparison at any discrete level throughout the laboratory do not exist.

1.2.e General Issue Summary. Air Force Doctrine, the national budget, the potentials for mismanagement, and indigent factors collectively suggest a real and current need for research and development project selection methodologies in DoD. Wright Laboratory has been chosen as the research institution for this study. Publication of the discrete criteria and aggregate comparison methodologies currently used may serve as a model for other military, civilian, institutions. Section 1.3 briefly introduces an additional study, lateral airfoils that exemplify a technological paradigm and is referenced extensively throughout the thesis.

1.3 Lateral Airfoils

This thesis uses lateral airfoils to secure information about Wright Laboratory R&D portfolio selection methodology. Lateral airfoils serve as a "research project placebo" during the interview process described in Chapter III. An understanding of lateral airfoil technology is needed before discussing the specific issue, research objectives, and research questions.

Lateral airfoils typify a technological paradigm, a new technology that the Air Force could research, but which is not currently being researched. Basically, as an aerospace vehicle design, they're easily understood through a comparison with helicopter main rotor blades. Helicopter blades "rotate" in a plane above the fuselage, or body of the helicopter. They provide lift and thrust to sustain flight. Lateral airfoils perform the same function, but in a different fashion. They "revolve" in a cylinder around or outboard of the fuselage.

This thesis marks the first formal introduction of lateral airfoils to the USAF research community. Chapter II summarizes three applications for lateral airfoil technology while Appendix A provides details of several patents. Technical applications of this technology include, but are not limited to, the following examples:

1. A new aerospace vehicle encompassing the qualities of a helicopter without the limiting effects on forward flight velocity resulting from retreating blade stall.

2. A new gas turbine engine design facilitating combined cycle engine technologies through combinations of lateral airfoil compressor and turbine sections with RAM jet engine technology.

3. A new naval propulsion system with applications on submarine, surface ship, and hydrofoil craft.

To date, there have been many United States government patents granted for lateral airfoils, albeit under many names. Lateral airfoil technology, if considered as a serious research candidate, would compete with both present and future Wright Laboratory projects. Given limited research resources like facilities, work force, and monetary funding, senior Wright Laboratory managers would either discard lateral airfoil technology, table research until some later date, or include it in a research program portfolio of some type. This research explores how Wright Laboratory approaches a decision on technologies like lateral airfoils.

1.4 Definition of Terms

An important part of understanding the specific issue and research questions is a grasp of the terminology commonly used by practitioners in the field of complex decision making. The following list includes words and phrases from *Analyzing Decision Making: Metric Conjoint Analysis* (Louviere, 1988:12) which are used in the remainder of this thesis.

Physical Variable: Observations or measurements of various physical antecedents of determinant attributes.

Attributes: Determinant decision criteria used by decision makers to evaluate research projects.

Position: Beliefs that decision makers have about the amount of each determinate attribute possessed by the research project.

Overall Utilities: The judgments, impressions, or evaluations that decision makers form on research projects, taking all the determinate attribute information into account.

Final Choice Set: The set of all potential research project discrimination criteria seriously considered prior to a decision maker's choice.

Choice: The cognitive process by which a decision maker, after evaluation all the possible viable research projects, decides to select one project, a portfolio, or to make no choice.

Part-Worth Utility: Judgments decision makers perform about "how good," "how satisfactory," or "how whatever" particular positions of particular products might be on particular determinant attributes.

1.5 Specific Issue

In a generic sense, the specific issue concerns the usefulness of cost estimates when compared with all possible factors considered in a research portfolio decision. The exacting language used with complex decision making, detailed in section 1.4, frames the specific issue as follows:

Specific Issue: Considering the proliferation of determinate attributes available to the decision makers, what is the part-worth of the cost estimate in a lateral airfoil research initiation final choice set?

1.6 Research Objectives

This thesis investigates the specific issue within the bounds of three research objectives. Again, the strict language of complex decision making is used. However, the objectives simply map the tools decision makers use to the degree used and addresses the usefulness of the engineering development cost estimate (a specific tool) in a research portfolio decision.

Objective 1: Solicit the determinate attributes that USAF decision makers use to discriminate between research projects with exceptional potential.

Objective 2: Evaluate the determinant attributes espoused by the decision makers by developing and describing a concept that Wright Laboratory as a whole has not previously researched.

The use of an independent mechanism, "research project placebo," forms the basis for the introduction and discussion of lateral airfoils.

Objective 3: The final objective is to seek a measure of an engineering development cost estimate's part-worth utility in Wright Laboratory's set evaluation criteria. In effect, to find the usefulness of the estimate. This objective is aided by using the placebo research project, lateral airfoils, to minimize the effect of familiarity with the technology.

1.7 Research Questions

The research questions illuminate the research objectives by focusing the thesis methodology on the objectives and guiding the research. The first question's language matches question one from Congdon's thesis (Congdon, 1988:7).

Question 1: What methods do managers use to select R&D projects and allocate laboratory resources at Wright Laboratories?

Question 2: What establishes lateral airfoils as a potentially viable research project?

Question 3: What determinate attributes do decision makers use in the final choice set during research program portfolio selection?

Question 4: What is the part-worth utility of an engineering development cost estimate in the decision maker's choice on a lateral airfoil design?

1.8 Scope

Currently the Air Force conducts research at four laboratories - Rome Laboratory, Phillips Laboratory, Armstrong Laboratory, and Wright Laboratory

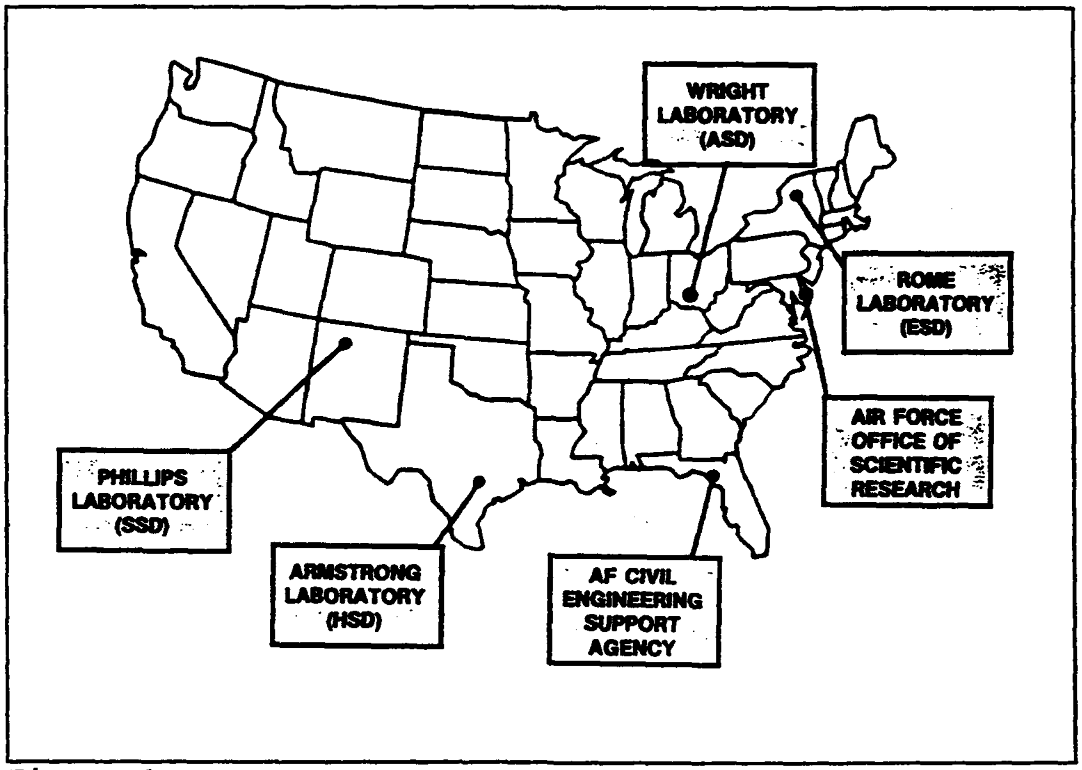


Figure 1. **Air Force R&D Organizations (Wright Laboratory Fact Sheet, 1992)**

(see figure 1). The Air Force routinely sponsors research at institutions outside the military environment that includes other government agencies, civilian universities, and public and private organizations. Within the Air Force, each lab has many directorates who manage both in-house research and research contracts with outside agencies.

This research investigates the decision making tools used in the R&D project selection process by decision makers within Wright Laboratory. The laboratory has seven directorates like the Aero Propulsion and Power directorate, the Flight Dynamics directorate, or the Materials directorate, each with decision makers at several levels: the Division Chief, Chief Scientist, Deputy Director, and Branch level. Since the population of decision makers outside the Wright Laboratory complex is extensive, this research uses only a representative cross-section of Wright Laboratory decision makers at Wright-Patterson Air Force Base, Ohio and Eglin Air Force Base, Florida.

1.9 Limitations

This research is limited to exploring the factors used to discriminate among potential research projects for Air Force categories of funding typically called applied research: Research, Exploratory Development, and Advanced Development categories. Since research project proposals are initiated from a variety of sources and levels within the government, this research further limits itself to the criteria, tools, format, and methodology that current laboratory managers use to dispense resources under their control.

1.10 Assumptions

This research assumes that decision makers will either consciously or subconsciously display bias when discussing projects under their management. Additionally, some Air Force projects are classified or subject to proprietary sensitivity. Lateral airfoils represent a unique, unclassified research project that relieves the tensions created by these assumptions.

1.11 Summary

Chapter I introduced the investigation t. . It described the general issue that is at the heart of the Air Force's ability to develop and exploit technology. The discussions included the effect of budget, mismanagement, and Air Force need on the general issue. The thesis' specific issue, research objectives and questions were all detailed using complex decision making language. The assumptions, scope, and limitations of the research completed the chapter.

While Chapter I laid the foundation for the literature review, Chapter II examines a variety of literature sources including Naval and Air Force research on DOD laboratory R&D project selection methodologies, patents, published sources, and artist conceptions. It develops and explains the concept basis for lateral airfoil technology and also includes an overview of R&D project selection methodologies.

Chapter III details the investigative methodology for examining the specific issue and four research questions. Each of the research questions required a tailored methodology that is addressed separately in Chapter III.

Chapter IV contains a discussion and analysis of the research results. The narrative begins with a consideration of the laboratory's response demographics, including parallel research demographics from 1985 and 1988. The results embrace familiarity and usage patterns within Wright Laboratory with published R&D project selection methodologies. Chapter IV ends with an assessment of the part-worth of an engineering development cost estimate, as a decision criteria, and a discussion of the research merit of lateral airfoil technology.

Chapter V completes the report of research conducted. It contains research conclusions and recommendations for future studies.

II. Literature Review

2.1 Introduction

This literature review examines four discrete topics. Wright Laboratory's organizational structure and mission serve as the first topic of investigation. Later discussions of laboratory methodologies and criteria build upon an understanding of laboratory responsibilities for its decision making environment.

The second topic discussed in section three of this chapter constructs a framework for examining R&D project selection techniques. Discussion of the technique selection issue and an overview of the nature and form of common methodologies is provided. However, the section references Appendix A for details of the different, published methods.

A Historical Perspective, section 2.4, reassesses prior studies on Wright Laboratory R&D project selection techniques and factors. The section incorporates the research findings of Brooks (1979), who modeled the laboratory decision process. The section also considers Congdon (1985) and Prince's (1988) investigation of the use of R&D project selection tools.

A fourth topic is covered in section 2.5, Lateral Airfoil Technology, which examines potential uses for lateral airfoils. Since many technological applications exist, the discussion is limited to one design each for an aerospace vehicle, gas turbine engine, and naval propulsion system. The section includes drawings and artist sketches.

2.2 Wright Laboratory

Wright Laboratory's heritage for advancing aviation technology dates from the very dawn of powered aviation. It begins in the 1900's when the Wright flyer thrust into the air over the rolling hills of America's heartland near Dayton, Ohio. The same ground that saw some of mankind's earliest, struggling airborne efforts, today holds a large government owned and operated research laboratory complex dedicated to continuing mankind's adventures into the "wild blue yonder."

Wright Laboratory is one of the four United States Air Force "Super Laboratories" which falls under the purview of the Aeronautical Systems Center (ASC). ASC's existence began on July 1, 1992 after the Air Force combined its System Command and Logistics Commands into a single entity. The merger led to reorganization and subsequent renaming of the former Aeronautical Systems Division to the current Aeronautical Systems Center. Today, each of ASC's four laboratories focuses on unique research disciplines. Specifically, the Wright Laboratory mission is to

> ***. . .lead and focus the Air Force's aeronautical technology investment by performing inhouse research and establishing contractual partnerships with universities and industry to:***
>
> > ***discover enabling technologies that offer potential for revolutionary improvements in the performance, affordability, and supportability of Air Force weapon systems.***
> >
> > ***develop and demonstrate advanced technologies for both current and future Air Force weapon systems to best meet our users' needs.***
> >
> > ***transition proven technologies to weapon system developers and maintainers in an aggressive, expeditious manner.***
> >
> > ***solve pressing technical problems wherever they occur through responsive support to any Air Force organization, 24 hours a day, in time of peace or war.***
>
> ***(Wright Laboratory Fact Sheet, 1992)***

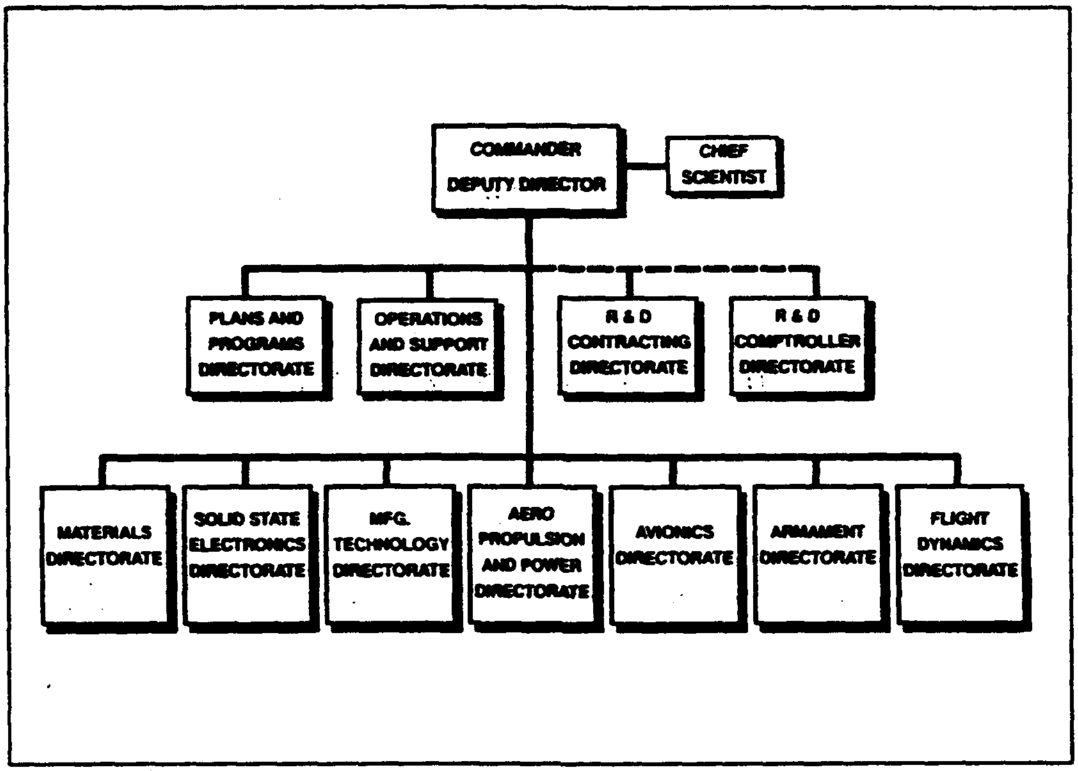


Figure 2. **Wright Laboratory Organization (Fact Sheet, 1992)**

Today's organizational structure for Wright Laboratory shows three support directorates, seven technology directorates, and a strategic planning directorate. Together, the command section and directorates employ over three thousand people (Wright Laboratory Fact Sheet, 1992). The 1993 organizational chart appears in Figure 2. The directorates operate in a united, synergistic effort meeting the overall mission through application of their discrete specialties. A description of each directorate's taskings follows:

> The Materials Directorate explores new materials and processes for advanced aerospace applications. Its current focus is on thermal protection materials, metallic and nonmetallic structural materials, aerospace propulsion materials, electromagnetic and electronic materials and laser-hardened materials.
>
> The Solid State Electronics Directorate is responsible for electronic device research and development in the areas of microelectronics, microwaves and electro-optics. Research extends from fundamental semiconductor layer growth and device fabrication through integrated circuits. In the electro-optics area, lasers, detectors and integrated focal plane arrays are developed.

The Manufacturing Technology Directorate serves as the focal point for planning and executing an integrated manufacturing program across the Air Force. In addition to a focus on manufacturing process technologies and computer integrated manufacturing, the directorate also focuses on design for producibility, design for quality, and design for life cycle costs, otherwise known as integrated product development.

The Aero Propulsion and Power Directorate focuses on airbreathing propulsion and aerospace power technology, which includes fuels and lubricants, turbine engines, and high performance/high mach air-breathing propulsion applications. Aerospace power research up to megawatt-class systems centers around electro-chemical energy storage, hyperconducting generators, and power conditioning subsystems.

The Avionics Directorate conducts research and development activities in the fields of offensive sensors (e.g., radar, infrared search and track, forward looking infrared), weapon delivery systems, reconnaissance, electronic warfare, navigation, communications, and avionics integration.

The Armament Directorate develops conventional armament technologies and integrates those into air-vehicle and other delivery platforms. The directorate provides conventional armament technology for four major thrusts which include advanced guidance, weapon flight mechanics, ordnance, and strategic defense.

The Flight Dynamics Directorate conducts the full spectrum of flight vehicle research. Primary areas of interest include structures, vehicle subsystems (landing gear, transparencies, etc.), flight control and aeromechanics. In addition, this directorate develops and maintains a fleet of experimental test vehicles to demonstrate integrated technologies --avionics, propulsion -- in an airborne environment.
(Wright Laboratory Fact Sheet, 1992)

Wright laboratory wielded a financial budget in excess of $950 million for fiscal year 1992, spending over $700 million on 1333 active contracts with 300 industrial and academia associates. Figure 3 shows that 76 percent of this money funded contract work outside the laboratory. Additionally, the laboratory evaluated and influenced "over 3,500 contractor Independent Research and Development (IR&D) projects involving approximately $2 B annually" (Wright Laboratory Fact Sheet, 1992).

Wright Laboratory statistics for 1992 include over 3090 personnel assigned with a ratio of an estimated 84 percent civilian and 16 percent military research-force. Less than one hundred enlisted servicemen formed the laboratory's ranks.

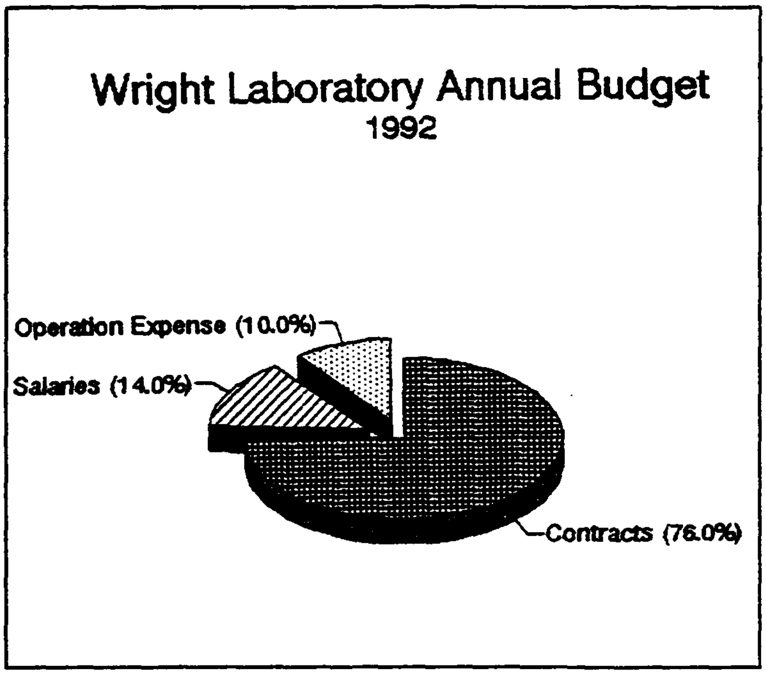


Figure 3. **Wright Laboratory Annual Budget (Fact Sheet, 1992)**

Not surprisingly, Figure 4 shows 80 percent of the personnel hold an engineering degree of some speciality with an additional 15 percent possessing math and science degrees. These sums include 283 technicians and nearly two thousand scientists and engineers.

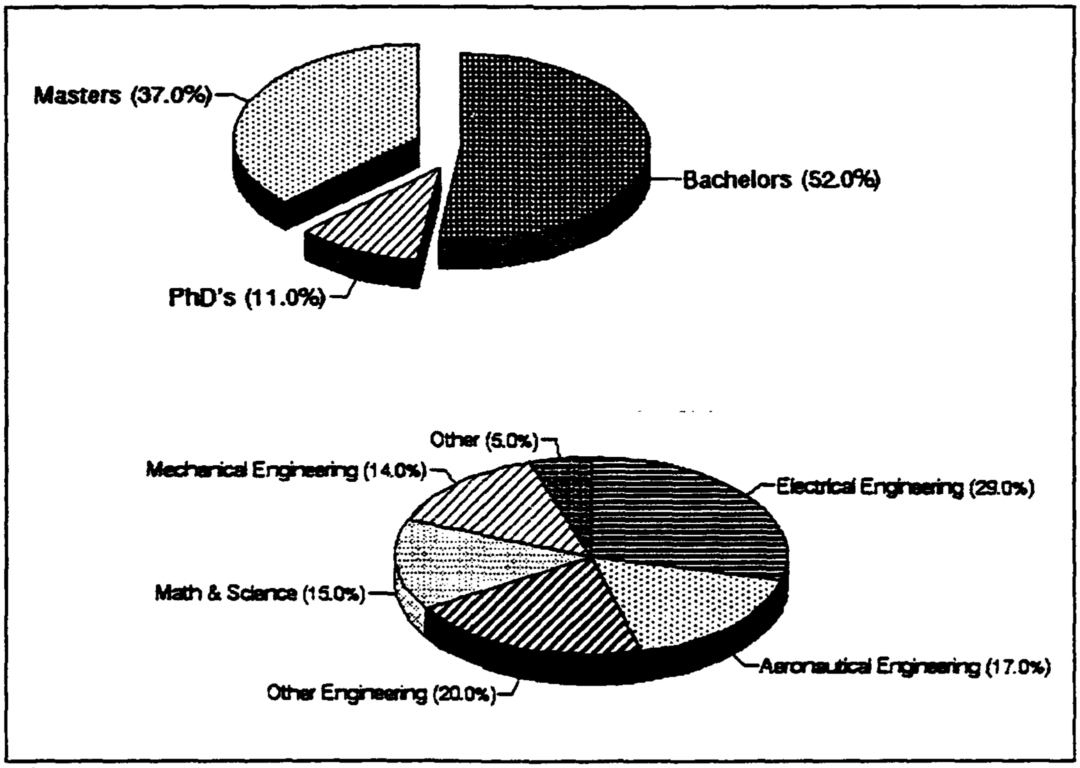


Figure 4. **Wright Laboratory Demographics (Fact Sheet, 1992)**

2.3 R&D Project Selection Techniques

Why use an R&D project selection technique? Are there different decision techniques available? To what degree is Air Force management interested in R&D project selection techniques? Which method is the best? These are all questions relevant to the thesis specific issue and the R&D community as a whole. This chapter introduces several techniques and notes their usefulness while Appendix A contains an informative overview of each technique.

Appendix A describes a variety of techniques using management style terminologies without using complicated mathematical formulas. It skims the discipline's surface without discussing methodological intricacies since a thorough understanding requires a lengthy study of volumous books and journal articles, many of which discuss only one technique or decision making method. Some writers suggest that "literally thousands of models" exist (Souder & Mandakovic, 1986:36). Therefore, Appendix A provides a cursory examination of published materials since a mastery of the subject requires more resources than this document affords. Fahrni and Spätig's (1990) research provides a deeper discussion of the subject and provides excellent guidance to managers making R&D model choices. Their investigation includes a binary decision tree procedure that leads to one of the "twelve archetypal groups of methods" for R&D project selection (Fahrni and Spätig, 1990). In other words, it helps managers pick a good technique. Additionally, a Naval Post Graduate thesis by Jordan (1992) furnishes an excellent overview of decision making methodologies of interest to the military manager.

2.3.a Is Project Selection Technique an Issue? Understandably, R&D decision makers must select projects to champion, cancel or delay. Often, individuals or agencies make these decisions through procedures used to allocate research money. A report requested by the US House of Representatives Committee on Science, Space, and Technology compared funding allocation methods used in federal research agencies. The Office of Technical Assessment (OTA), responding to a Congressional request, published the results of more than 125 interviews conducted with managers at all levels in its report, *Federally Funded Research: Decisions for a Decade* (Robinson, 1991:575-577). The report concludes that

> ***. . . setting priorities can help to allocate federal resources both when they are plentiful, as they were in the 1960's, and when they are scarce, as is expected through the early 1990's.***
> ***(Chubin & Robinson, 1991:B1-2)***

This OTA document not only confirms high level bureaucratic interest in decision making methodologies, but it begs the question, "is something wrong with the current system?" Indeed, some government executives and at least one OTA analyst have questioned the current decision making process.

> ***Top policy makers in Congress and the Executive Branch, as well as officials at research agencies and scientists themselves, have acknowledged that the nation would benefit from clearer, more deliberate selection of where and how research dollars are spent. Preserving the pluralistic, decentralized system of federal support for research that has served well for 40 years now requires better structures for making choices within that system.***
> ***(Chubin & Robinson, 1991:B1-2)***

Many documents reveal DoD's interest in the subject. Prior to the OTA report, research project selection processes served as the focus for many Department of Defense (DoD) initiatives. The abundance of graduate research alone confirms this premise (Brooks, 1979; Prince, 1985; Congdon, 1988; and Jordan, 1992) and suggests DoD's sustained interest in R&D resource allocation as well.

2.3.b Nature and Form of Techniques. Humans suffer from many constraints that preclude consistency in good decision making. One of these constraints, bounded rationality, recognizes our finite intellectual capacities. Formal decision making models reduce the effects from this constraint, and a myriad of other potential fallacies, by providing techniques for structuring the decision problem, clarifying the alternatives, and logically formatting the selection process. While the procedures do not replace a decision maker, they certainly enhance an individual's or organization's decision making stability and continuity. They also help safeguard the decision's relevant factors from improper weighting or other bias. Jordan notes eight potential mitigation factors in the decision process:

> ***1. Filtering bias***
> ***2. Experience bias***
> ***3. Giving priority to information by order received***
> ***4. Memory capacity limitation***
> ***5. Conformity to prior beliefs***
> ***6. Causal chains of likely outcomes limitation***
> ***7. Risk preference bias***
> ***8. Independence of the future from the present***
> ***(Jordan, 1992:29)***

Assuming the need for an appropriate decision making technique, how does one explore the subject? Do literary sources support a hierarchy subdivision of the methodologies? Several authors have approached this exploration impasse and, unfortunately, they have chosen different paths, which, perhaps, reflect their unique perspectives. With little doubt, the ubiquitous proliferation of classifications for decision making techniques reflects the general abundance of methodologies and confounds the exploration issue. In the following two examples note that the first author divided the subject into four groupings while the second author chose two different categories.

It is useful to classify the population of project selection models as classical methods, portfolio models, project evaluation techniques and organizational decision methods. (Souder and Mandakovic, 1986:36)

The methods proposed in literature for project evaluation and selection can be classified into two categories. One is the class of compensatory models, which reduce a multi-dimensional evaluation to a single-dimensional one through an aggregating "value" function, thereby establishing tradeoffs between criteria. Cost/benefit analysis, Multi Attribute Utility Theory (MAUT) and Analytical Hierarchical Process (AHP) can be cited as examples for this category . . .

The other category of methods for R&D project evaluation and selection is that of noncompensatory models, where tradeoffs between attributes are restricted. One group consists of Multiple-Criteria Decision Methods of the ELECTRE family . . .

(Oral, Kettani, and Lang, 1991:871-2)

Fortunately, for the purposes of this thesis, it is unnecessary to determine or champion a particular categorization or grouping. It is critically important, however, that the reader understands that diversities of techniques exist. The techniques often use fundamentally different procedures that are premised upon widely different philosophies. Congdon (1988), referencing the works of Stephen Cooley, et al. (1986), and John Gibson (1981), proposed a grouping alternative different from the two prior references. The format provides a convenient springboard for a cursory examination of the subject and with only minor modification, serves as the pattern for Appendix A.

1. *Scoring models*
2. *Economic models*
3. *Constrained optimization models*
4. *Decision theory models*

(Congdon, 1988:30)

2.4 A Historical Perspective

This section provides an appraisal of three prior AFIT theses on R&D project selection methods at Wright Laboratory, formally known as Air Force Wright Aeronautical Laboratories. These documents record the Air Force's sustained interest in R&D decision making processes and point toward an overall DoD interest. Their material span the decades of the 1970's to the 1990's. The documents are presented in chronological order beginning with the first thesis by Air Force Captain Terry L. Brooks titled ***Policy Capturing of Management Personnel through Project-Selection Decision Making in an Air Force Research and Development Laboratory*** (Brooks, 1979). A second selection, by Jeremy R. Prince, ***Research and Development Project Selection Methods at the Air Force Wright Aeronautical Laboratories***, addresses how Air Force managers select research projects to create a laboratory portfolio (Prince, 1985). The third thesis, ***Factors Affecting the Adoption of R&D Project Selection Techniques at the Air Force Wright Aeronautical Laboratories***, authored by Jonathan D. Congdon expands on Prince's research and presents the Air Force Wright Aeronautical Laboratory managers' attitudes, perceptions, and adoption affecting variables for research portfolio selection (Congdon, 1988).

2.4.a Brooks Study. In the mid to late 1970's Doctor's Michael J. Stahl and Adrian M. Harrell of AFIT conducted extensive interviews within Wright Laboratory. They successfully isolated six factors that laboratory personnel contends were used during R&D project selection (i.e. the factors laboratory decision makers judged as critical). They were

> 1. ***Cost-Benefit Ratio***
> 2. ***Technical Merit, characterized as new or better capabilities***
> 3. ***Resource Availability, the availability of personnel, equipment, or facilities***
> 4. ***Likelihood of Success, the probability of achieving technical success within the time constraints***
> 5. ***Time Period, based upon the estimated project completion time***
> 6. ***Air Force Need, or the degree that the Air Force had articulated a need.***
>
> ***(Brooks, 1979:87)***

Captain Brooks employed this information in a policy capturing instrument and then surveyed laboratory decision makers, partitioning them by level, division, and type of laboratory project. His goal was to model individual laboratory members and determine if a consensus on decision making criteria existed among management levels and within laboratory directorates. Brooks tested eight specific hypothesis and found that Wright Laboratory managers indeed used all six factors identified by Stahl and Harrell (Brooks, 1979:89). Additionally, he determined that:

> ***. . . there was not a consensus in the decision making process among managers of the management levels of the 6.3 projects, or the managers in the divisions of the 6.2 and 6.3 projects. Also, the managers of both projects did not use a decision making process exactly the same as that which they perceived. (Brooks, 1979:89)***

Brooks' findings suggest that Wright Laboratory managers could not correctly articulate the model(s) they actually used.

2.4.b Prince Study. Prince's research focused on exactly how Wright Laboratory managers selected their research projects. He used a personal and telephone interview technique to fulfill ten specific objectives. His research provides the first historical data base on the seven technical constituent labs of Wright Laboratory known today as Directorates. Prince's study included demographic data on the managers surveyed. His findings detail formal R&D decision method awareness, technique use, and the laboratory's desire to change project selection methodology. He also recorded laboratory decision maker ratings on the importance of various research project selection factors.

Prince concluded that the "top three factors" in project selection were: Air Force need or organizational goals, technical merit, and resource availability

(Prince, 1985:37). He noted that only 30 percent of the respondents interviewed used formal decision making methods. This may appear as a surprisingly small fraction since the remaining 70 percent of the interviewed respondents made their decisions without the help of formal decision making tools.

Prince also identified a laboratory wide phenomena that formal decision making formal methods, when employed, were "relatively simple to learn and easy to use" (Prince, 1985:38). Although many respondents were aware of formal decision making techniques, usage was low. Apparently, the only exceptions were cases with relatively large budgets. Prince attributed this behavior to a feeling expressed by many respondents that "most of the decision making tools are impractical because of disharmony with the existing laboratory management style and the technical weakness of the methods" (Prince, 1985:38).

Further, Prince found low positive response to any initiative to change decision making methods in the laboratories, a finding that dramatically changed in the years between Prince and Congdon's research. Prince noted that formal training had little impact on decision making methodology and deduced that formal methods were used by upper management because they were "under greater scrutiny than managers at lower levels" (Prince, 1985:39). He also found that the use of formal decision methods escalated with the dollar values of the projects or portfolios involved.

2.4.c Congdon Study. Congdon validated many of Prince's findings. His thesis pursued three research objective's which roughly paralleled Prince's objectives. Specifically Congdon wanted to know:

1. ***The methods used by managers to select R&D projects and allocate resources;***
2. ***The attitudes and perceptions of managers toward the use of formal R&D project selection techniques; and***
3. ***The factors affecting the adoption of these techniques by R&D managers.***

(Congdon, 1988:35)

Congdon surveyed 43 Wright Laboratory managers, all occupying the position of Deputy Division Chief or higher. He selected twelve managers, three from each directorate, for intensive follow-up interviews. Interestingly, Congdon's research, occurring three years after Prince's, established that the survey respondents "in general, are not familiar with most R&D project selection techniques" (Congdon, 1988:61). He confirmed Prince's earlier observation that formal R&D project selection technique use was limited, although his respondents expressed a desire to learn more about the different techniques. Congdon noted that Material Laboratory's (now known as Material Directorate) project selection process tended to be "somewhat more structured" (Congdon, 1988:69).

Congdon documented an Air Force environmental effect he titled "requirements pull" which motivated managers to demonstrate R&D benefits of a specific program in economic terms. Additionally, he writes, ". . . respondents indicated that budget constraints force managers to select those R&D projects which are less risky, and provide immediate short-term benefits" (Congdon, 1988:71).

Congdon also noted little likelihood that any existing formal technique could adequately consider all relevant Wright Laboratory decision making criteria due to the following:

1. ***The input data required by formal techniques would be difficult to develop***
2. ***The mathematics involved with the quantification of project selection decisions was more complex than necessary***
3. ***The outputs from the potential techniques would yield irrelevant information.***

(Congdon, 1988:76)

Perhaps Congdon's observations explain the disparity between decision makers' willingness to change procedures and documented lack of change.

2.5 Lateral Airfoil Technology

This section provides a designer's glimpse of three applications for lateral airfoil technology. Lateral airfoils typify a technology that the Air Force could research. Bibliometric evidence from United States patents granted for specific applications on aerospace vehicles exist and serves as the springboard for discussion of the concept and its use in this study.

The lateral airfoil patent designs shown in Appendix B represent what many inventors considered as a truly remarkable discovery or innovation for their time. The patents captured both the designers' dreams and best understanding of the concepts. A summary presented in Appendix B acknowledges the designers' contributions to lateral airfoil understanding and establishes a trend that offers unique operational characteristics and enhanced capabilities for aerospace flight. However, it is important to note that with aerospace vehicles, a patent does not establish airworthiness.

2.5.a Aerospace Vehicle. An easy way to explain lateral airfoils is to compare them to known and well understood technology. Today's helicopter serves this roll since most people have witnessed the helicopter's unique flight characteristics like hover, vertical takeoff, and vertical landing. During these maneuvers the helicopter generates lift from its main rotor blades to overcome the other forces acting on the vehicle, like gravity. If one considers a helicopter sitting on the ground, as the main rotor blades spin faster and faster while the blade pitch is increased, the vehicle slowly rises vertically into the air. Likewise, if the pilot decreases the main rotor blade pitch or allows the blade to slow, then the vehicle settles gently to the ground. The main rotor blade spinning about the vertical axis of the vehicle, makes all this happen.

A lateral airfoil produces the same forces as a helicopter main rotor blade. The only difference is in the axis of movement. Lateral airfoils revolve around the

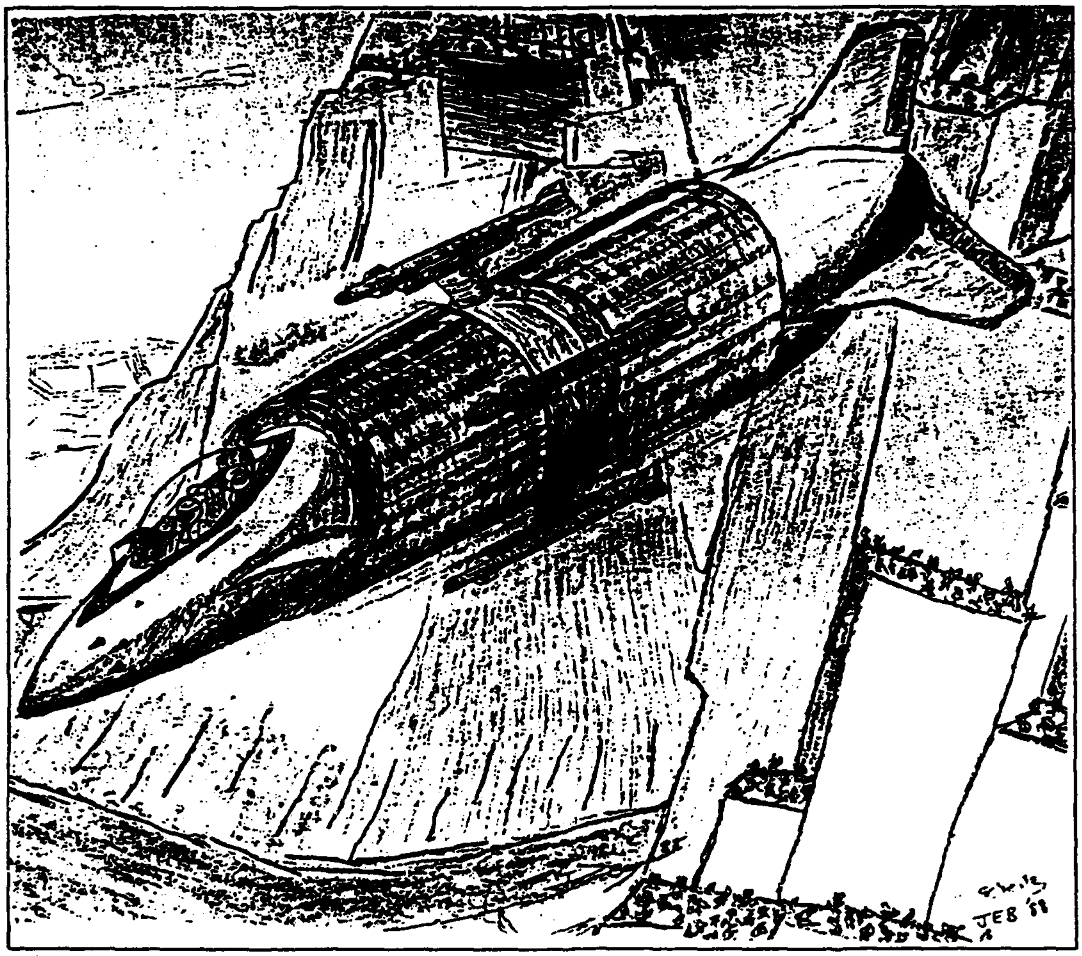


Figure 5. **Lateral Airfoil Aerospace Vehicle Design**

vehicle's horizontal axis, while the helicopter's main rotor blades rotate about the vertical axis. The aerodynamics follows all known laws. A deeper discussion of the flight forces, control mechanisms, and capabilities of the lateral airfoil aerospace vehicle appears in Appendix C.

The artist's conception in Figure 5 presents a classic military fighter design with landing gear retracted. Notice that the design uses more than one blade just as helicopters usually use more than one blade on top. Also, the aerospace vehicle exploits more than one set of blades. This allows better roll axis control because the blade sets counter-rotate and eliminate torque.

Helicopters produce much air movement. This is most noticeable near the ground by the characteristic main rotor blade down-wash. Likewise, the lateral airfoil produces a downwash effect, which if left unducted would build inside the vehicle's fuselage. The artist concept ducts the down-wash out the back of the craft producing a forward thrust component.

There are many novel lateral airfoil designs documented with the federal government. Every attempt has been given to exhaustively survey all pertinent United States Patents and present them in Appendix B, but one or more patents may have been overlooked that describe or significantly enhance knowledge on lateral airfoils. The patents and descriptions presented in the appendix were gathered through a patent search commissioned by the author in 1978 and updated through a LEXIS data base search using the key phrases: (rotat! or mov!)+(wing or airfoil)+(lateral w/5 airfoil).

2.5.b Gas Turbine Engine. For the purposes of this discussion, one may characterize the gas turbine engine's operation in basic terms. An axial flow engine draws fresh air in the front or intake, pressurizes it through successive stages of compression, mixes fuel with the highly compressed air, ignites the mixture, uses a turbine to extract some portion of the energy from the air to power the compressor, and blasts any super hot air remaining out the engines aft. The engine gets its name from the idea that the air flows in a straight or axial fashion from intake to exhaust.

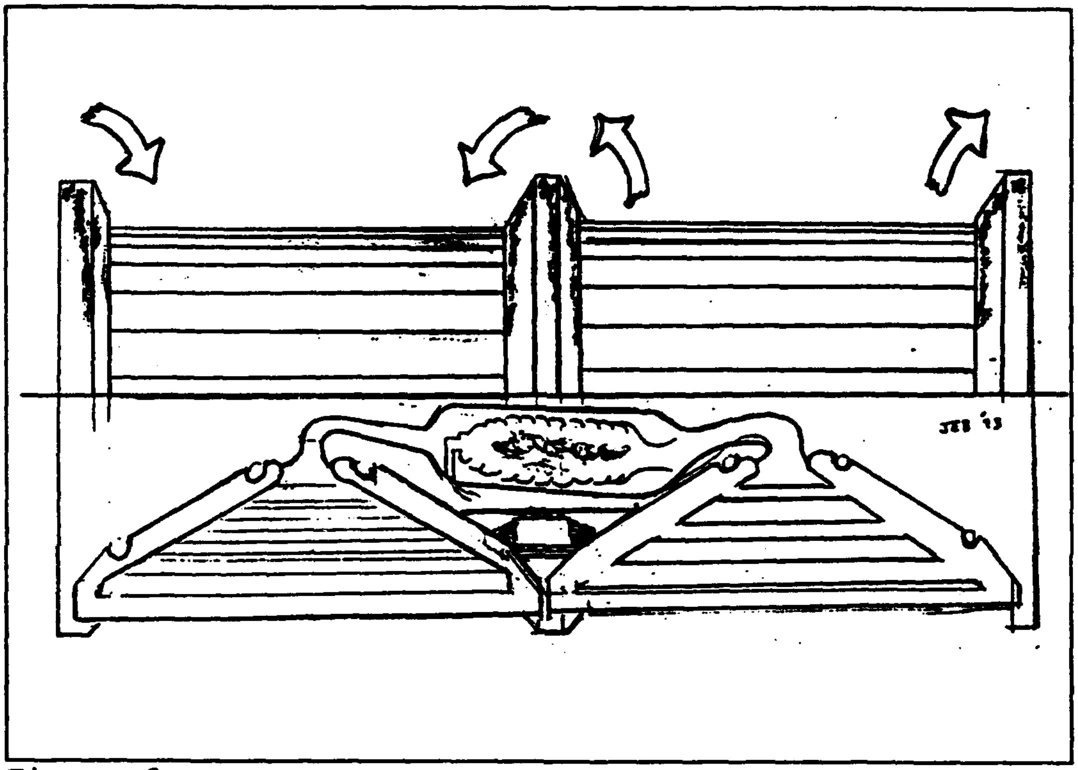


Figure 6. **Lateral Airflow Cyclone Engine**

Figure 6 shows a lateral airfoil gas turbine engine unlike any known design. Yet, it shares much in common with the 'traditional' axial flow counterpart. Recall that the lateral airfoil aerospace vehicle characterized in section 2.5.a suffered from a down-wash phenomena where air pressure built up inside the vehicle's fuselage. One might characterize this as a vice since, if left unchecked, it would destroy the vehicle. However, with gas turbine engine applications this vice becomes a virtue.

Figure 6 also shows the intake air coming into the engine from the sides. Air enters from all 360 degrees. The lateral airfoils perform the same function as compressor blades. As the blades revolve around the engine's longitudinal axis they draw air down deeper into the core. This looks like a cyclone effect to a casual observer and may serve as an appropriate name for the engine. Just as with the gas turbine engine, there may be more than one stage of compression.

The lateral airfoil compressor and turbine blades have advantages over their counterparts in the conventional axial flow engine. These benefits stem from the fact that the blades are supported on both ends. First, one can make longer blades to pull in larger volumes of air. Secondly, if the volume of air required remains the same, than the blades can be made lighter since they don't have to carry the same amount of stress at their root. Other benefits arise as well. For example, the engine can produce massive amounts of thrust without requiring a large diameter frontal area. The removal of the large flat compressor disk reduces the vehicle air drag. Finally, although not exhaustively, the engine demonstrates better low observable characteristics since the big, radar reflecting, compressor disk becomes a longer, thinner axial member.

The burner section of the lateral airfoil engine may look similar to its counterpart on the axial-flow engine, but the turbine section makes a radical departure. Lateral airfoil turbine blades revolve around the engine's longitudinal axis and extract heat energy from the hot, compressed air in much the same fashion as a conventional turbine blade. The fluid passage way gradually expands as the air surfaces from the engine core. The successive stages of turbines extract needed energy to drive the lateral airfoil compressor section while the remaining energy is ducted for some useful purpose.

One may visualize a compressor drive shaft located on the engine's exterior as opposed to an axial-flow design where the drive shaft sits in the engine's core. This also presents some unique characteristics since the shaft can be split into more than one, but what is more important, the engine centerline section is now free for other uses. For example, one could employ a lateral airfoil compressor and turbine section on the engine's outer surface area and place a ram jet in the center. This, of course, would offer unique combined cycle propulsion capabilities. Alternatively, one could use an axial flow compressor or turbine sections with an appropriate lateral airflow complement to produce still more radical design combinations each with its own unique capabilities.

One can see, without much engineering rigor, that lateral airfoils offer unique capabilities.

2.5.c Naval Propulsion. Naval technology applications lay outside the normal research work of Wright Laboratory. Yet, the lateral airfoil or, more correctly, the lateral hydrofoil applications follow so naturally that they merit a cursory mention here.

Lateral hydrofoil fluid dynamic applications offer a new dimension for technology employment. A concept drawing of the lateral hydrofoil dynamic propulsion appears in Figure 7. The foil's characteristics parallel the Voith-Schnider propeller designs common in marine applications. In fact, one may envision the lateral hydrofoil as a Voith-Schnider propeller rotated 90 degrees. The lateral hydrofoil can produce many of the same thrust vectors found in a Voith-Schnider blade, especially if the blades are helixes. However, there are some distinct differences.

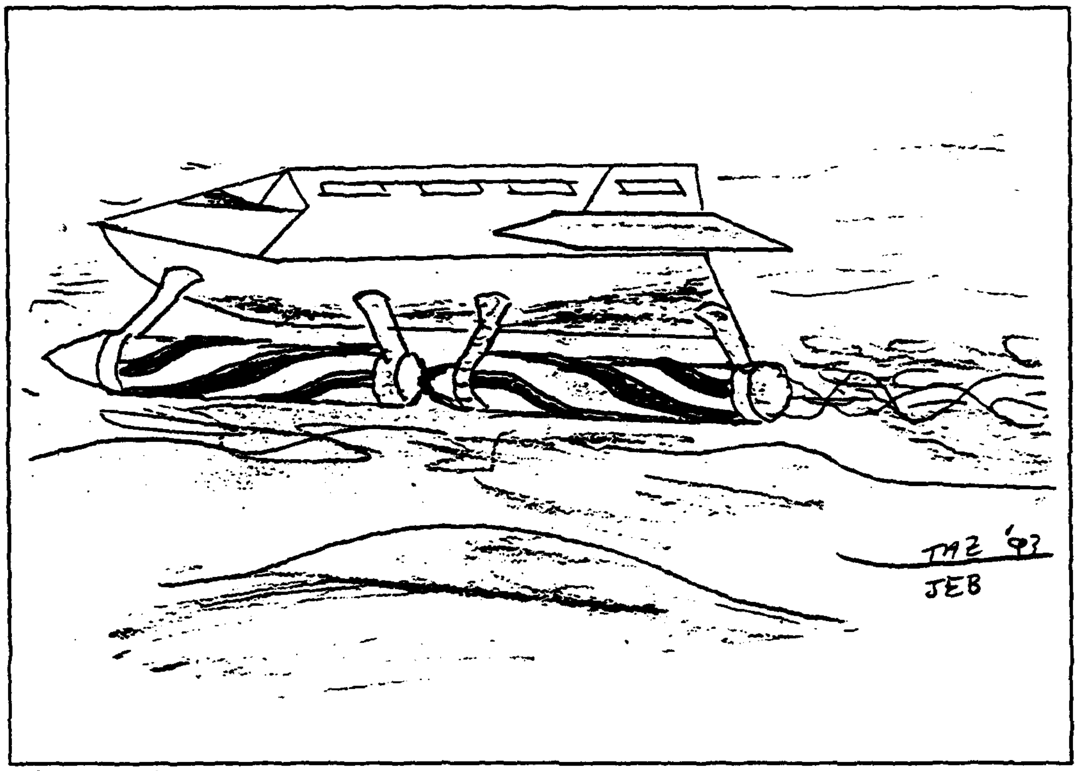


Figure 7. **Lateral Hydrofoil Dynamic Propulsion Application**

One noticeable difference between the Voith-Schnider propeller and the lateral hydrofoil is the placement of the foil. The lateral hydrofoil can be partially or fully submerged and it yields a thrust vector created from the fluid buildup in the center of the revolving blades. Further, the lateral hydrofoil, if fashioned with substantial blade/foil widths and helix, can support the vehicle while propelling it at high speed.

2.6 Chapter Summary

The literature review began with a discussion of Wright Laboratory, including its organizational structure, mission, and demographics. A survey of R&D project selection techniques followed. The nature and form of the techniques were briefly sketched while the reader was referred to Appendix A for a deeper discussion, including the strengths and weaknesses of each category by methodology. Next, past research on Wright Laboratory with material focused on three AFIT research theses from 1979 through 1988 was presented. Finally, the chapter ended with a comprehensive overview of lateral airfoil technology. The discussion included an aerospace vehicle, gas turbine engine and naval propulsion applications. Again, deeper discussions of the topic appear in the Appendix A. The next chapter explores the research methodologies used to secure the answers for the questions generated from the specific issue identified in chapter I.

III. Methodology

3.1 Introduction

This chapter builds from the research questions and the prior studies discussed in Chapters I and II. It explains how lateral airfoils were used to gather information on Wright Laboratory's decision making criteria. The following paragraphs recount the methodology used to explore the specific issue while meeting the research objectives and answering the research questions. Generally, the research methodology synthesizes answers for the investigative research questions through three techniques, surveys, a patent search, and interviews. The format for discussing the methodology follows the investigative questions as listed in Chapter I. Each of the investigative questions highlighted a unique facet of the research objectives and used a tailored methodology.

3.2 Question 1: Project Selection Methods

What methods do managers use to select R&D projects and allocate laboratory resources at Wright Laboratories?

Previous research by Prince (1985) and Congdon (1988) offers both a historical basis for understanding the decision making process and a variety of research tools to explore this question. Further, their research results contribute a benchmark with which to measure Wright Laboratory decision maker change, retrenchment, or progress with formalized decision making techniques. This research determines whether the laboratory has enhanced older published techniques or initiated new methodologies in recent years.

Both Prince and Congdon collected demographic data and respondent attitude data on Wright Laboratory's managerial preference on many formal project selection techniques (Congdon, 1988:38). Their results define the parameters for the historical data base that will be scrutinized in conjunction with the results of this study.

Congdon's research text included his copy of a choice survey questionnaire. He adapted his survey instrument from a "Likert-based instrument provided by Dr. William Souder, a professor at the University of Pittsburgh" (Congdon, 1988:4). Congdon states that, "because the instrument was developed by an expert in the field of implementation research, its internal validity was not questioned" (Congdon, 1988:37). However, experts in Likert based survey formats may find some fault with specifics of Congdon's instrument. Despite obvious limitations, this research uses Congdon's instrument. Re-administrating Congdon's survey instrument in this thesis facilitates many concurrent and historical analysis options. Additionally, it creates a consistent research survey data base, albeit with unknown instrument validity, for future research. The fact that approximately four years elapse between research on this aspect of Wright Laboratory has not been overlooked.

Prince, the first researcher delving into Wright Laboratory, used an interview questionnaire with many of the same questions asked later by Congdon (Prince, 1985:43-55; Congdon, 1988:93-98). A cursory inspection reveals that, despite many similarities, Congdon employed a much richer survey format asking more in-depth questions than Prince. Congdon's form fills three sections and spans eleven pages (Congdon, 1988:93-98). Prince's interview format rests on three pages (Prince, 1985:43-45). While Congdon's survey instrument was chosen as a more appropriate information gathering device, note that some minor changes were needed to reflect the widespread organizational restructuring and renaming that has affected Wright Laboratory since 1988. A copy of the 1993 survey appears in Appendix D.

The specific methodologies used in this research effort differ from both Congdon and Price. The 1993 survey mailing list includes a representative sample of Wright Laboratory Directorates. Each branch received two surveys based upon the Air Force internal distribution system. A short discussion here may prove useful to readers unfamiliar with the internal military mail address structure.

The Air Force uses letters to represent various offices. Usually, more important offices in an organizational hierarchy have fewer letters in their office symbols or mailing addresses. For example, a Directorate might have a two letter office symbol like PQ. Typically, organizations directly below, and within a directorate, share the same first two letters plus their own unique identifier. So, a division might be PQR in this example. The 1993 survey sample was stratified using this hierarchy format. One survey went to each Directorate level, two letter office symbol. The Division levels, with three letter office symbols, also received one survey. Lower tier offices, with four or more letters, all received two surveys each. In total, Wright Laboratory received three hundred thirteen surveys or one survey per ten people.

3.2.a Survey Instrument Part 1. Survey questions one through sixteen (see Appendix D) identify decision maker familiarity and extent of usage with published R&D project or portfolio selection techniques (Congdon, 1988:93). The responses to these questions were processed with the SAS/STAT software package. The package produces both descriptive statistics and variability information on the survey data. Statistically significant response variance among the Wright Laboratory Directorates was analyzed using a Kruskal-Wallis non-parametric test process on AFIT's Academic Support Computer. This Kruskal-Wallis procedure carries no restrictive assumptions of respondent data 'normality'. Congdon notes that the Kruskal-Willis test is an appropriate procedure because of "its robustness and conservatism" (Congdon, 1988:40). Stratification of the sample population by directorate enables sub-population data analysis while giving greater procedural flexibility for the different strata (Emory, 1980:167). However, not all directorates were included in this procedure. The study was limited to Plans and Programming and the seven technology directorates. Results from the data analysis follow in thesis Chapter IV.

Questions' 17 through 28 used Likert-based questions to "measure the respondent's attitude and perception toward the use of formal project selection techniques" (Congdon, 1988:38). Again, SAS/STAT provides descriptive analysis and variability information on the data where appropriate. The analysis employs a Kruskal-Wallis non-parametric test for respondent variability between the directorates. However, many of survey questions 17-28 lay beyond the domain of the 1993 research and the results are not addressed in this study.

3.2.b Survey Instrument Part 2. Part II of the survey seeks information on "management's willingness to adopt formal R&D project selection techniques" (Congdon, 1988:8). While this information was not needed for the study, it was retained to preclude unexpected interaction effects resulting from removing this survey instrument section. An edited survey instrument might compromise data comparisons with Congdon's earlier survey. Part II, therefore, remained in the 1993 survey. The data is included in the data base (see Appendix E), however, an analysis of the data is left for future study.

3.2.c Survey Instrument Part 3. This section, with questions 59 through 70, addresses demographic, budgetary, and training data (Congdon, 1988:97-98). Again, the SAS/STAT software package provides both descriptive and variability information. One cannot compare the 1993 results with 1985 or 1988 without first understanding the respondent demographics.

3.3 Question 2: Lateral Airfoil Research Viability

What establishes lateral airfoils as a potentially viable research project?

Narratives and drawings presented in Chapter II detailed some of many, potential lateral airfoil applications. In addition, Appendix A's patent search shows trends with the design through the years. Together, these two sections establish the research potential of lateral airfoil technology. Establishing an answer to question is pivotal to the investigation. The stakes are high because, if the lateral airfoil project appears too ridiculous, then it becomes unsuitable as a research project placebo. This, in turn, compromises the entire "criteria" data collection process discussed later in this chapter.

The bibliometric approach looks to literature, historical records, and other media sources for a trend. If enough bibliometric evidence surfaces, than, to a certain degree, it established lateral airfoil technology's viability for institutional research. Specifically, if a long term trend exists showing increased understanding and sustained interest in aerospace applications, then lateral airfoils may hold some research potential for Wright Laboratory.

Patents represent one body of bibliometric evidence for investigation. They are ideal mediums. Gaining access to the United States patents records requires only moderate levels of effort. Furthermore, as legal documents, they carry high credibility. Additionally, computer search services like LEXIS that maintain patent data bases, grant researchers an expanded capability. The computer can successfully isolate appropriate patents by using a "key word" search process. The data collection effort includes a LEXIS key word search using the following format: (rotat! or mov!)+(wing or airfoil)+(lateral w/5 airfoil). Results from the quest appear in Appendix A.

A validation test for bibliometrics' adeptness at predicting research potential was included with the interviews described later. Each interview participant gauged the potential of lateral airfoil technology. They were asked if they would support, oppose, or table the placebo project. The responses, processed with the SAS/STAT package, appear in Chapter IV.

3.4 Question 3: Attributes Used in Portfolio Selection

What determinate attributes do decision makers use in the final choice set during research program portfolio selection?

Compared with Prince or Congdon's prior research, this question explores a distinctly deeper stratum in the decision making process. It sets the stage for subsequent modeling of the Wright Laboratory decision process. The criteria gathering methodology must, therefore, provide credible determinant attributes that can fit into a model. Techniques available for building a decision model vary, but include the methodology employed by Brooks (Brooks, 1979) and Metric Conjoint Analysis as described by Louviere (Louviere, 1988). In an effort to maintain some consistency, the 1993 data collection method uses a typical metric conjoint analysis, opinion measurement tool.

The exploratory nature of the determinant attribute identification process suggests a personal interview format for the data collection method (Emory and Cooper, 1991:146). Indeed, one prior Air Force research thesis documents the results of interviews on this subject conducted by Doctors Stahl and Harrell of the Air Force Institute of Technology (Brooks, 1979:89). Unfortunately, Brooks' work fails to describe how their criteria were distilled. Since an accurate decision making model presupposes valid determinant attributes, the 1993 research targets this material void.

An interview format affords the best opportunity to explore the issue, but researcher time proved a limiting factor at AFIT. The 1993 interview schedule hinged on securing the Wright Laboratory sample within a constrained period of three weeks. Cost, in dollars, for data collection presented no problem, but the time span allocated for the interviews had to fit into fifteen work days. A disproportionate stratified sampling technique was chosen (Emory 1980:168-169). Throughout the period, thirty-six interviews were conducted for a sampling rate of one percent of the population.

Emory cautions that a small sample size based on convenience has little status (Emory 1980:177). But, he rejects, as folklore, the belief that sample size must bear some proportion (ie., 10 percent) to total population size (Emory 1980:153). In fact, Emory notes that simple stratification may be more efficient than random sampling with disproportionate sampling yielding even greater efficiencies. The interview schedule employed a disproportionate sample of Wright Laboratory constituents using approximately six interviews per directorate. Some support directorates were excluded from the interviews because they lacked a research thrust. The interview schedule also considered disparate organization within the lower organizational levels. For example, some directorates possess no section levels within their entire organization. Within directorates that have section levels, all branch levels may not have equal numbers of sections under their authority. Finally, because the directorates used to be independent laboratories prior to the creation of ASC's four "super laboratories," not all branches perform equal management roles. Therefore, the agenda included interviews with two participants each at levels of directorate or division, branch, and section for Wright-Patterson Air Force Base as appropriate.

The typical interview format includes a brief introduction for the interviewer and participant which usually last one to two minutes. Following the introductions, each participant received a five minute cursory overview of the lateral airfoil placebo project. Since lateral airfoils' proffer a radical appearance, they serve as an easy medium for discussion. Further, they are so unknown that participants approach the technology at roughly the same level of innocence. As the interview progresses, the determinant attributes articulated by the participant are documented on the bottom margin of the interview guide response sheet that is included in Appendix F. For instance, if the decision maker questions the design cost or technical merit, then those two determinant attributes were recorded on the interview guide along with all other discrimination parameters. Please note that the interviewer does the writing during this "brain storming" session.

However, after the participant exhausted his/her personal set of determinant attributes, then they were asked to review a draft list of attributes recorded on the interview guide. From this point forward, the participant makes all necessary marks on the interview guide. The participants are first asked to record the draft criteria in their own words. Participants are encouraged to expand or delete criteria from their "brain storming" list as appropriate. Then participants marked their opinion on the utility of each of their final criteria. A one hundred-fifty-millimeter line mark scale, common with metric conjoint studies, serves as the measurement devise.

Emory and Cooper caution against potential interview problems. "In personal interviews, the researcher must deal with two major problems: bias and cost" (Emory, 1991:327). A need for unbiased information requires that the interviewer not alter the questions or otherwise influence the interview subject. An interview guide furnishes the best chance for minimizing this type of error. The constrained time limit focused the scope of this research on subjects geographically near Wright-Patterson Air Force Base. This constraint, however, virtually eliminates cost as a factor. Bias, then, remains as the only potential interview problem.

Characteristically, bias can occur from three factors: sampling error, response error, and nonresponse error. Regrettably, some sampling error surfaces in the 1993 interviews since the sample population of Wright Laboratory decision makers may not truly represent the normal population qualities for decision makers from the past, present, or future.

Nonresponse error proves negligible since the interviews were scheduled throughout a three-week time span allowing more than one interview opportunity. Response error persists, then, as the single largest element capable of injecting bias into the survey. Using a single interviewer and a written interview guide/response sheet safeguarded consistent interview format and accurate data collection.

The interview guide/response sheet also included the six determinant attributes used by Brooks in his 1979 modeling effort. Each participant rated the criteria's utility on a line mark scale labeled at the extremes with low utility or high utility. Ultimately, the respondents' opinions on lateral airfoil technology provide insight into the true determinant attributes used in the 1993 Wright Laboratory decision making process. Once all criteria are known, then the most frequently used or more important factors can be distilled. The SAS/STAT package provides descriptive and variability statistics for this data investigation. The frequency rating given, when compared with other determinant attribute's frequency ratings, shows the criteria's utility. In the case of a tie between two or more criteria, the mean rating serves as the discriminate.

3.5 Question 4: Effect of Cost Estimate

What is the part-worth utility of an engineering development cost estimate in the decision maker's choice on a lateral airfoil design?

As noted, question three's interview guide includes the six determinant attributes used in Brooks' Wright Laboratory study. Additionally, it included a seventh potential determinant attribute, a cost estimates for the lateral airfoil aerospace vehicle of $210 million. Each of the thirty-six subjects rated their opinion of the engineering development cost estimate on the same type of one hundred-fifty-millimeter line mark scale described earlier.

SAS/STAT procedures calculated the mean point estimate utility score for the engineering development cost attribute. Comparing the cost estimate's mean utility score with the other six determinant attributes rated at the same time, by the same subjects, should reveal its utility. A higher point estimate of the mean utility score than Stahl or Harrell's original six criterion suggests the decision maker feels that the criterion has greater utility. Likewise, a lower mean score than other determinant attributes' shows lower utility in the opinions of the participants.

3.6 Chapter Summary

This chapter detailed the methodology used to explore the specific issue and answer the research questions. Overall, the research methodology synthesizes the answers through a battery of techniques including patent search bibliometrics, mailed surveys, and personal interviews. The next chapter displays the results of the surveys and personal interviews along with an analysis and discussion.

IV. Results and Discussions

4.1 Introduction

This chapter offers a discussion and analysis for both the survey and interview responses. The survey instrument described in Chapter III and included in Appendix D were mailed June 4, 1993. Mass mailing followed coordination with the Wright Laboratory Commander and the chief scientist. Appendix D also contains a copy of the cover letter that introduced both the survey and interviews. The interviews, following closely on the heels of the survey, were conducted throughout the weeks of June 7, 1993 through June 28, 1993.

Three hundred thirteen surveys were mailed to Wright Laboratory personnel working at Wright-Patterson Air Force Base, Ohio and Eglin Air Force Base, Florida. One hundred thirty-two usable surveys were returned within thirty days of the mailing. The survey return rate of 42.2 percent is consistent with other written survey, mass mailing return rates. While most respondents completed all three sections in the instruments, a few surveys were returned with one or more sections incomplete. Completion of at least one survey section served as a minimum requirement for its measurements' inclusion in the analysis data base. Some surveys were returned with either blank pages or an explanatory note. The notes, if any, were excluded from the response data base and the survey was eliminated from the count of returned documents. This chapter also includes an analysis and discussion of data exchanged during the personal interviews. Demarcation and utility measurement of decision making criterion for laboratory personnel at

Wright Patterson AFB, Ohio served as the focus for the thirty-six interviews. The survey and interview results presented in tables, graphs, and narrative format throughout this chapter provide a basis for summarizing the decision making criteria and formal methods used in a large United States government research and development laboratory.

4.2 Demographic Data

Demographics presented throughout the adjoining pages define range boundaries for survey respondents only. Care should be taken not to confuse the survey demographics with interview demographics. In fact, few demographics were collected during the exploratory interviews since the endeavor focused on Wright Laboratory as a whole. The survey respondents provided demographic data including their age, civilian grade or military rank, gender, educational level, and organizational affiliation. This data appears in tables, graphs, and narrative format throughout the next several pages. Please note that, where applicable, appropriate comparisons with the earlier research results of Prince (1985) and Congdon (1988) appear with the 1993 results. These comparisons establish trends for Wright Laboratory from 1985 through 1993.

Figure 8 and Table 1 detail respondent distributions, separating them by level within Wright Laboratory. A full 40 percent of the 1993 respondents worked at the middle organizational tier or branch level. Identical numbers of responses returned from both the upper, division level and lower, section levels.

Earlier researchers studying Wright Laboratory used differing methodologies. Prince chose a sample of ten people each from the Avionics, Aero Propulsion & Power, Flight Dynamics, and Materials Directorates. His sole criterion for a participant was "that the individual be involved in selection of an in-house research project" (Prince, 1985:23). Congdon mailed his survey to a "non-random sample of respondents occupying positions of Deputy Division Chief or higher" (Congdon, 1988:35). While the 1988 survey instrument compares favorably with the 1993 version, the sample mailing population differs. The 1993 survey mailing

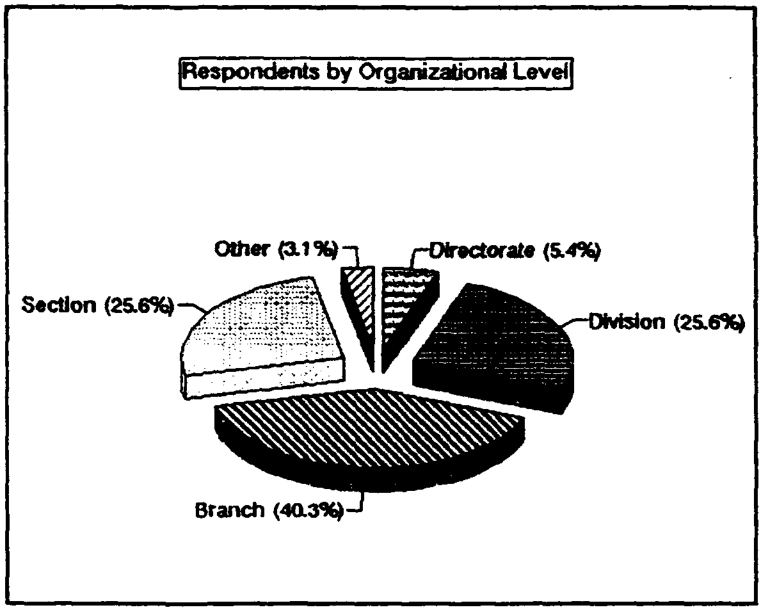


Figure 8. **Survey Respondents by Organizational Level**

Distribution of Respondents by Organizational Level

Level	Frequency	Percentage
Directorate	7	5.43
Division	33	25.58
Branch	52	40.31
Section	33	25.58
Other	4	3.10
Total	129	100.00

Table 1. **Distribution of Respondents by Organizational Level**

list included a ten-fold increase in sample size for a broader representative cross section of today's larger Wright Laboratory organization. It included section, branch, division, and directorate levels. The 1993 cosmopolitan sample provides greater confidence that survey results generalize to Wright Laboratory as a whole. Unfortunately, this expanded generalization ability sacrifices some direct response comparisons with the earlier research. However, the 1993 results should compare favorably with other large corporate, educational, and Department of Defense research organizations.

4.2.a Age Data. The distribution of survey respondents by age shows nearly 60 percent of the personnel range in age from 46 through age 55 and over. A small fraction of the respondents came from the age groupings 20 - 30. This ratio shows that the respondent share a propensity for a seasoned perspective on R&D techniques. As the 1993 results are compared with prior years, please recognize that subtle population differences may obscure or exacerbate genuine variation in respondent distributions. For instance, Congdon

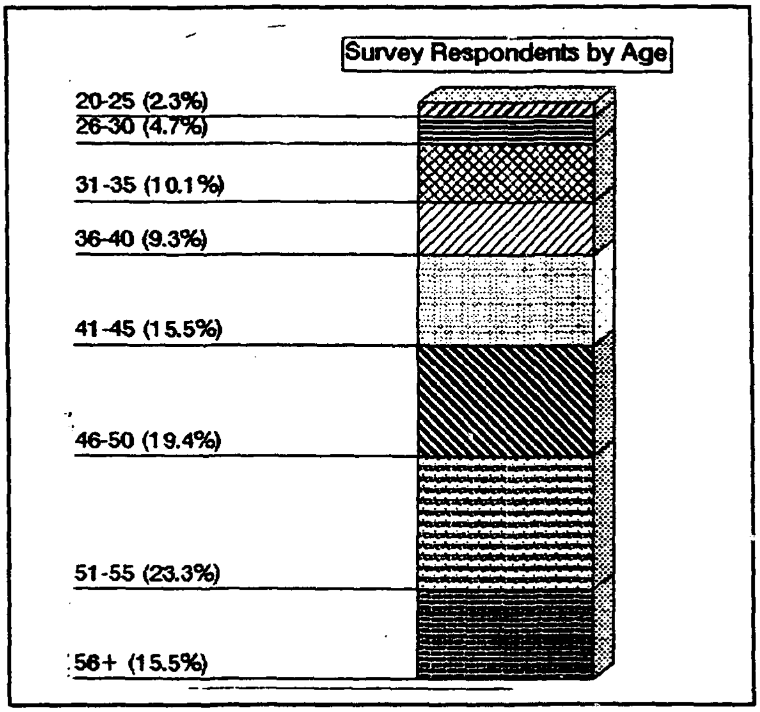


Figure 9. **Survey Respondents by Age**

recorded no respondents below the age of thirty-five and only one response through age forty. The 1993 survey results show 20 percent of the respondents in these categories. Clearly, Congdon's age distribution results from the senior supervisors sampled, the Deputy Division Chiefs or higher, who are usually older. These age distributions influence interpretation and comparison of formal technique familiarity and usage responses presented later in this chapter.

4.2.b Gender. Do all respondent aberrations stem from elementary sample population age differences? No, consider the respondent's gender as an example. The 1993 survey response distribution includes a 7.75 percent female population (see Figure 10). Congdon secured zero female responses with his survey (Congdon, 1988:46). It's unknown if this difference produces any measurable impact since 8 percent is such a small population change. However, subtle sample differences like gender generate repercussions frustrating direct comparisons between this and prior research and necessitate a certain degree of correlation error between 1985, 1988, and 1993.

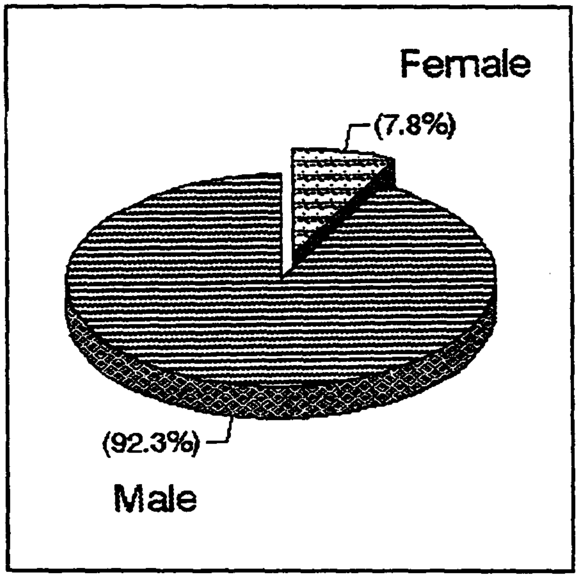


Figure 10. **Respondents by Gender**

Other researchers may also have an interest in this gender proportion which further explains its inclusion here.

4.2.c Directorate Representation. Staff organizations present another arena for dissimilarity through the years of data collection on Wright Laboratory. Figure 11 and Table 2 show the distribution by organization as a

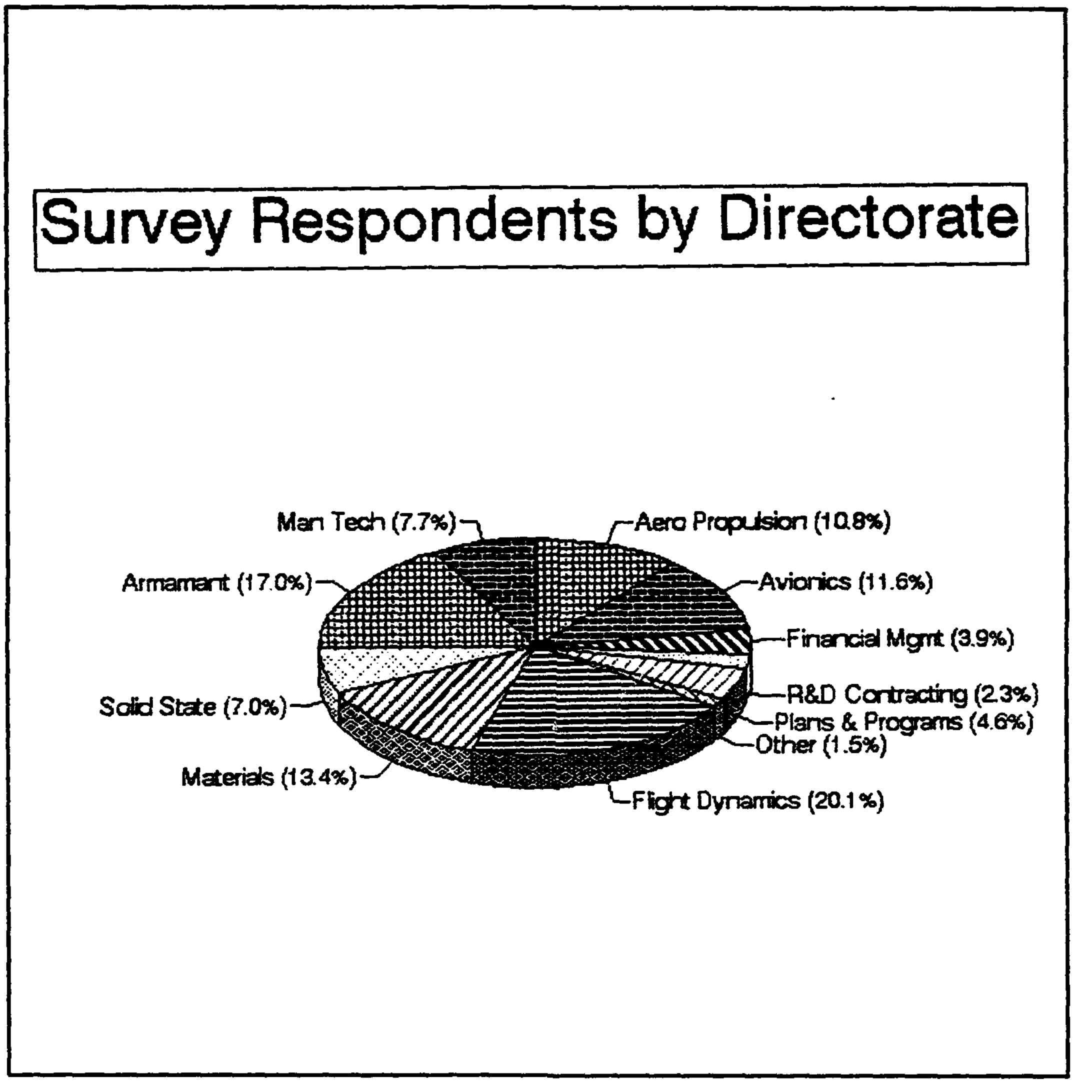


Figure 11. **Survey Respondents by Directorate**

percent of total respondent population. One can see that Flight Dynamics Directorate personnel account for 20 percent of the respondents.

The 1993 survey results appearing in this figure include the staff organizations. This differs from prior researchers. Prince solicited an equal ratio of respondents from Avionics, Aero Propulsion & Power, Flight Dynamics, and Materials Directorate. Congdon included these and other organizations, but excluded staff structures from his survey (Congdon, 1988:36). Typically, Congdon's missing staff

Distribution of Respondents by Organization

Organization	Frequency	Percent
Aero Propulsion	14	10.94
Avionics	15	11.72
Flight Dynamics	26	20.31
Materials	16	13.50
Solid State Electronics	9	7.03
Armament	22	17.19
Manufacturing Tech	10	7.81
Financial Management	5	3.91
R&D Contracting	3	2.34
Plans & Programs	6	4.69
Other	2	1.56
Total	128	100.00

Table 2. **Distribution of Respondents by Directorate**

organizations encompass R&D Contracting and the Operations and Support Directorates. However, please note that the 1993 respondent distributions from the staff account for only 3.9 percent of the total respondent population.

4.2.d Degree. This statistic reveals a very educated sample population for 1993 (see Figure 12). The respondent's distribution by highest educational degree shows that 80 percent possess a master's degree or higher educational level. This demographic reveals a great deviation from the laboratory's published real statistics of 48 percent (see Figure 3). It suggests that any decision making technique familiarity and usage percentages presented later may disproportionately reflect the opinions of Wright Laboratory's more educated personnel. One would assume that such a well educated cross section would possess an extensive exposure to a variety of decision-making methods. However, this assumption proves invalid considering data presented later in this chapter. Figure 13 suggests a steady decrease in Wright Laboratory senior educational levels since 1985. However, the decreased ratio of Doctorate degrees may result from 1993's inclusion of a larger number of personnel below the Deputy Division Chief level.

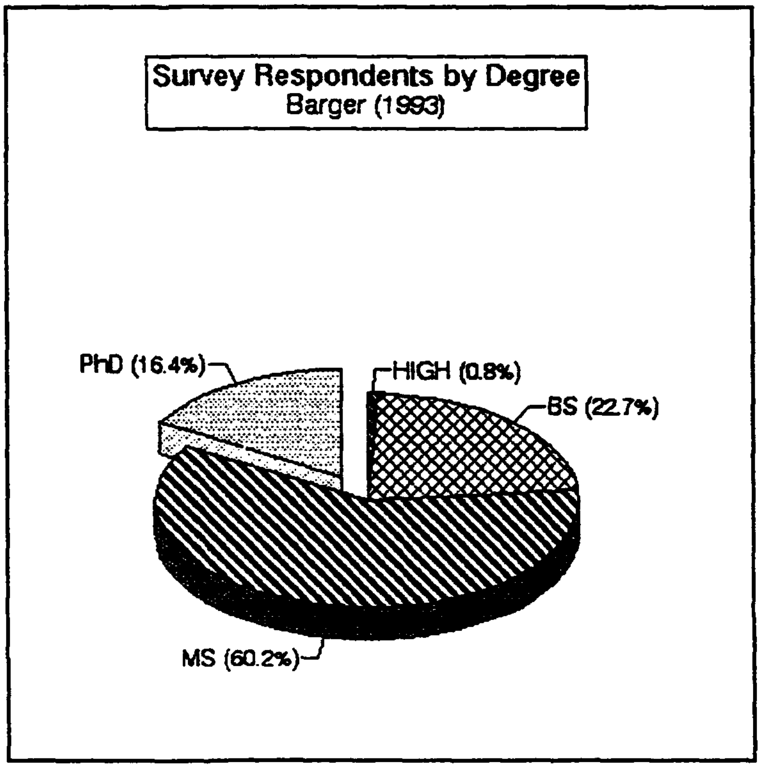


Figure 12. **Survey Respondents by Degree**

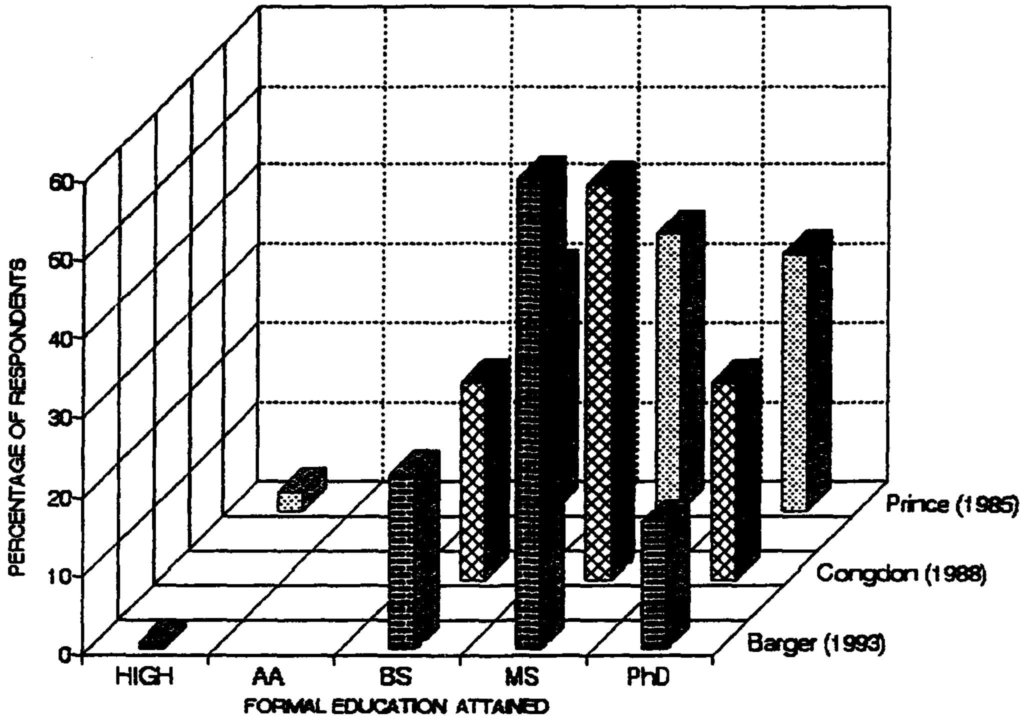


Figure 13. **Summary of Respondents by Highest Educational Degree**

4.2.e. Degree Major. Some might question whether the degree major represents an important demographic for discussion. If one contends that certain Masters level educational curricula should include courses in Laboratory Management, Operational Science, or Decision-making Methods, then these statistics may prove useful.

Most of today's Wright Laboratory respondents majored in an engineering discipline (see Figure 14 and Table 3). This tracks well with the laboratory's published demographics showing an 80 percent engineering degree research force (see Figure 2). Comparing this study with prior research reveals that it tracks

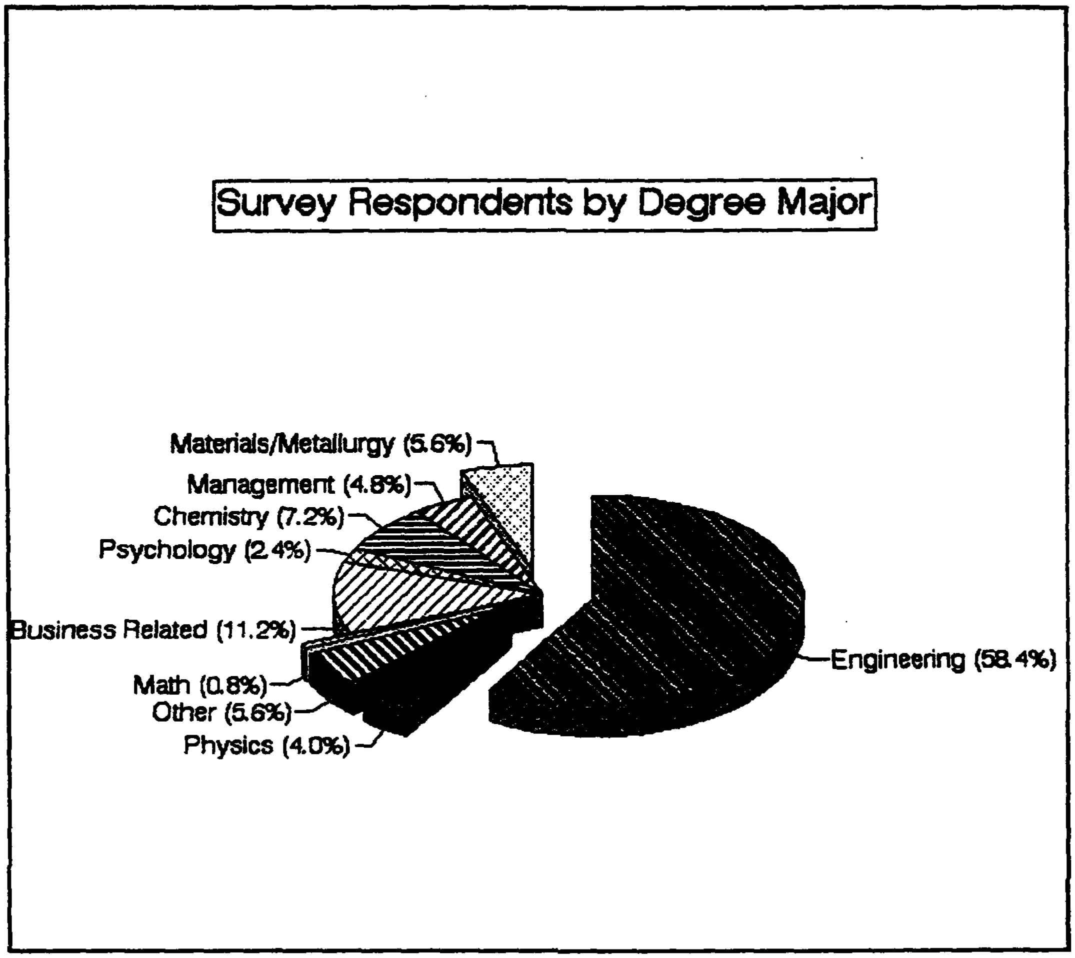


Figure 14. **Survey Respondents by Degree Major**

closer with today's laboratory population than Prince who identified 65 percent of his respondents as engineers (Prince, 1985:48). The second most fashionable 1993 major was a business-related study. Please note that despite its number two ranking, business and management majors accounted for only 16 percent of the total respondent population.

Distribution of Respondents

Major Field of Study in Highest Degree Granted

Major	Frequency	Percentage
Physics	5	4.00
Math	1	.80
Engineering	73	58.40
Business Related	14	11.20
Chemistry	9	7.20
Management	6	4.80
Materials/Metallurgy	7	5.60
Psychology	3	2.40
Other	7	5.60
Total	125	100.00

Table 3. **Distribution of Survey Respondents by Degree Major**

4.2.f Course-work. Laboratory management curricula's completion rate was at nearly 80 percent for 1993 (see Table 4). This high figure for such a

Distribution of Pespondents by Applicable Course-work

Courses Attended	Frequency "Yes"	Percent "Yes"	Frequency "No"	Percent "No"
MS/OR	79	61.24	50	38.76
Lab Management	100	77.52	29	22.48

Table 4. **Distribution of Survey Respondents by Applicable Course-work**

widely distributed sample displays a sound educational background. Differences among this study and Prince and Congdon's research efforts could be sample size dependent (see Figure 15). If the decrease varies with the sample population, then other related indices should exhibit a comparable 10 percent decline. Interestingly, the percentage of course work completed in Management Science/Operational Research has fallen by 20 percent in the same period comparing the same sample populations (see Figure 16).

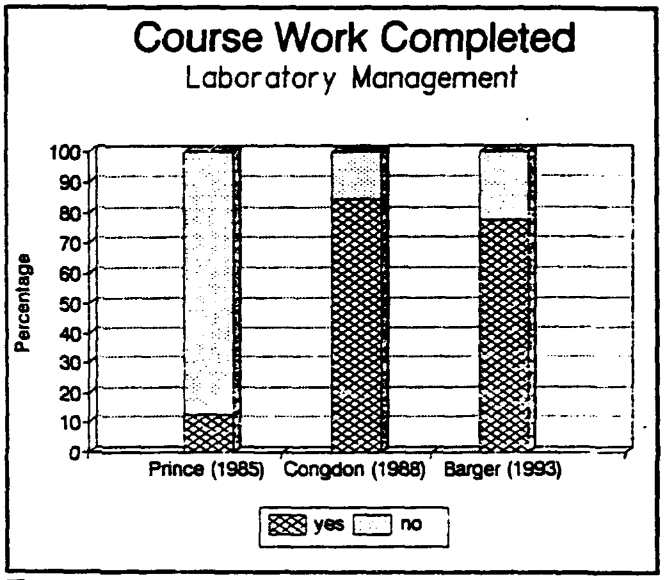


Figure 15. **Percentage Respondents Completed Laboratory Management**

Potential explanations for this inconsistency span a range from the pessimistic tenet suggesting the results spring from a general disenchantment with management science, operations research and laboratory management disciplines to the positive hope that the results reflect a growing degree of specialization within these fields. Whatever the underlying cause, these demographics point to a potential for decreased familiarity with formal R&D project selection techniques simply because people have had fewer exposure opportunities for the materials. Interestingly, the next section shows that an inspiring percentage of respondents said they would be "willing to attend a seminar on formal R&D project selection techniques."

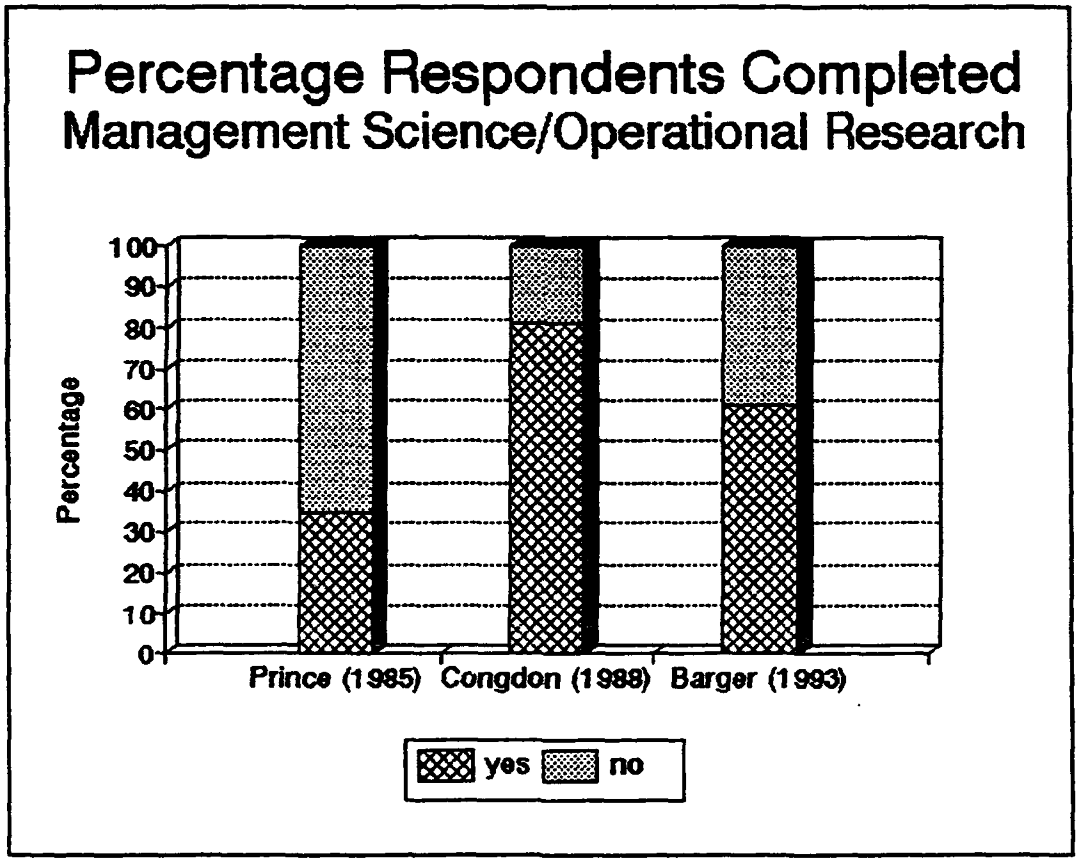


Figure 16. **Percentage Respondents Completed MS/OR**

4.2.g Willingness to Attend Course. In the 1993 survey, 76 percent of the Wright Laboratory population responded positively to this query (see Figure 17). This statistic suggests a keen interest in the topic and compares positively with 80 percent identified by Congdon in 1988. One rational for today's interest may stem from the large number of respondents, 91 percent, who acknowledged that a technique might prove beneficial to them. Comparison with other researchers suffers somewhat on this demographic since Prince's statistics were void of information on respondent willingness to attend R&D Project Selection classes.

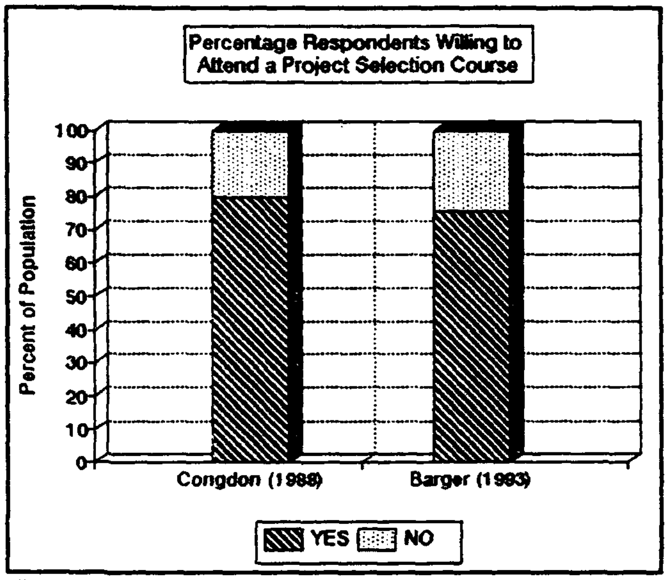


Figure 17. **Percentage Respondents Willing to Attend a Course**

4.2.h Grade or Rank. Please recall that both the 1988 and 1993 survey instruments were essentially identical. However, some data from 1988 is unavailable for comparison. One such measurement missing from Congdon's research is respondent rank or civilian grade. Since these demographics may prove useful, the next few pages present it and other important indicators such as budget responsibility and discretionary research percentages. These demographics have a potential impact on survey comparisons with Prince and Congdon's research.

Wright Laboratory serves the United States Air Force as one of its' four owned and operated "super laboratories." One unfamiliar with these national

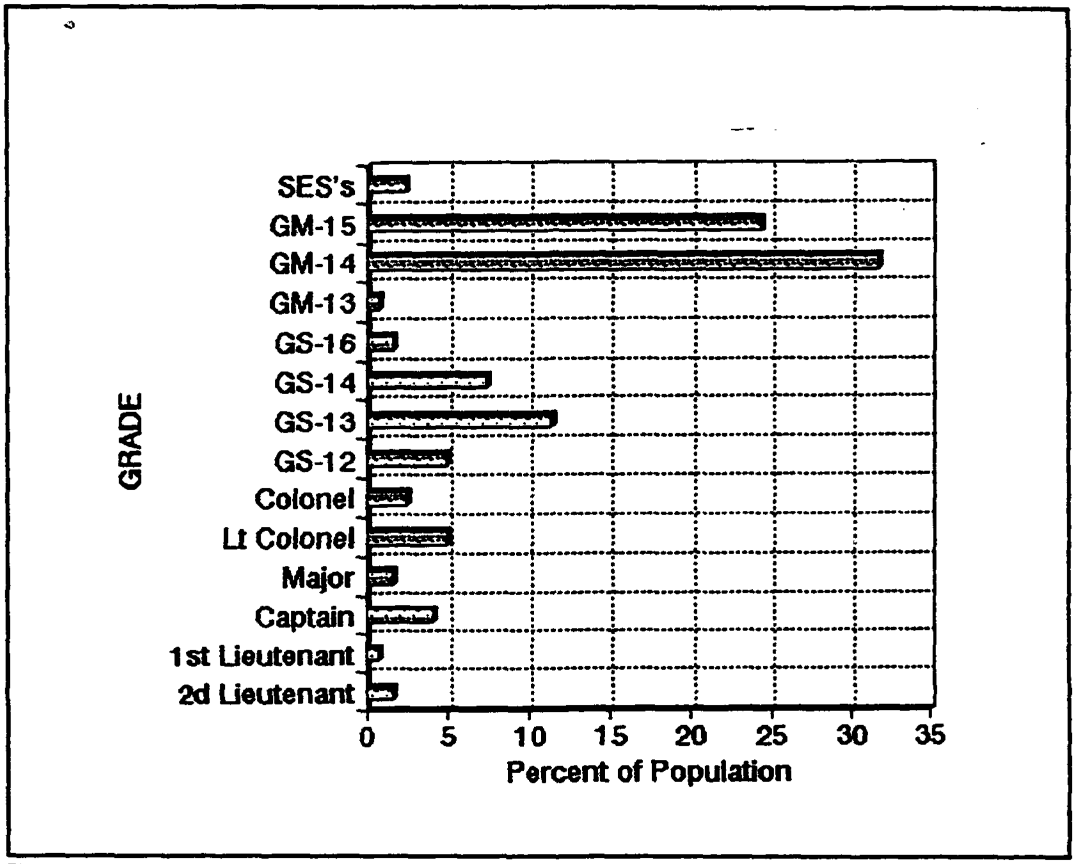


Figure 18. **Respondent Percentage by Grade or Rank**

resources might assume that their military posture dictates a purely military population. In reality, most of Wright Laboratory's proletarian remain civilian. The published ratio of civilian to military for the laboratory gives an 84 percent civilian population (Wright Laboratory, 1992). The 1993 survey respondents match this population figure giving an 85 percent civilian population (see Table 5 and Figure 18). Prince, despite sampling a different population, shares this observation, recording nearly an equal percentage of personnel (87.5%) in 1985 (Prince, 1985:46).

Distribution of Respondents by Civilian Grade or Military Rank

Grade	Frequency	Percentage
2d Lieutenant	2	1.63
1st Lieutenant	1	.81
Captain	5	4.07
Major	2	1.63
Lt Colonel	6	4.88
Colonel	3	2.44
GS-12	6	4.88
GS-13	14	11.38
GS-14	9	7.32
GS-16	2	1.63
GM-13	1	.81
GM-14	39	31.71
GM-15	30	24.39
SES's	3	2.43
Total	123	100.00

Table 5. **Distribution of Survey Respondents by Military Grade or Civilian Rank**

4.2.i Budget. As shown in Figure 24, 85 percent of the respondents replied that they were responsible for at least $1 million annual budget authority. This contrasts with Prince who found 60 percent responsible for $1 million or more. However, Prince uses 1985 dollars while this study uses 1993 as the base year. The large sums of money managed reflects the heavy educational level and research expertise required and also impacts both civilian and military grade structures within Wright Laboratory. Readers familiar with grade structures may have noticed an absence of military enlisted rank, Wage Grade or lower tier GS personnel in the data presented.

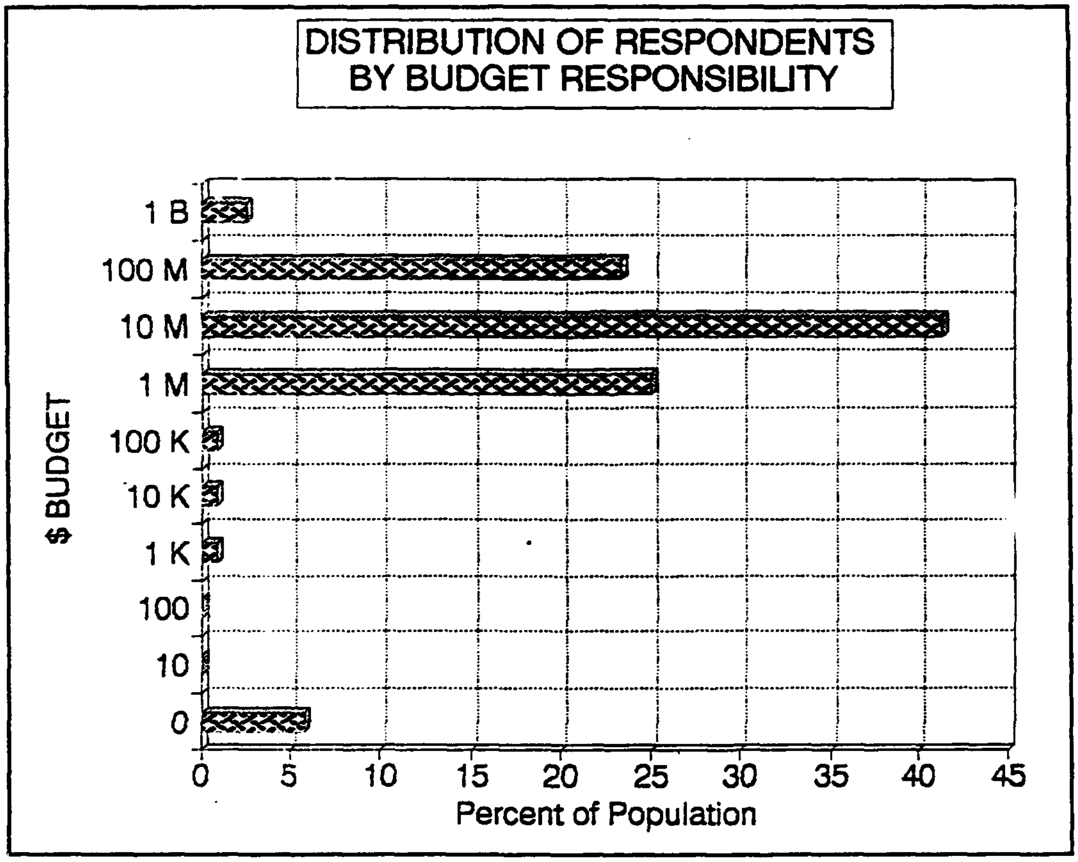


Figure 19. **Respondent Percentage by Budget**

4.2.j In-House Research. One half the respondents indicated that 30 percent or more of their budgets were spent in-house, while 13 percent contracted out 90 percent or more of their research. Figure 20 shows that a majority of respondents reported a large contract budget which compares favorably with a published laboratory statistics of 76 percent (Wright Laboratory Fact Sheet, 1992).

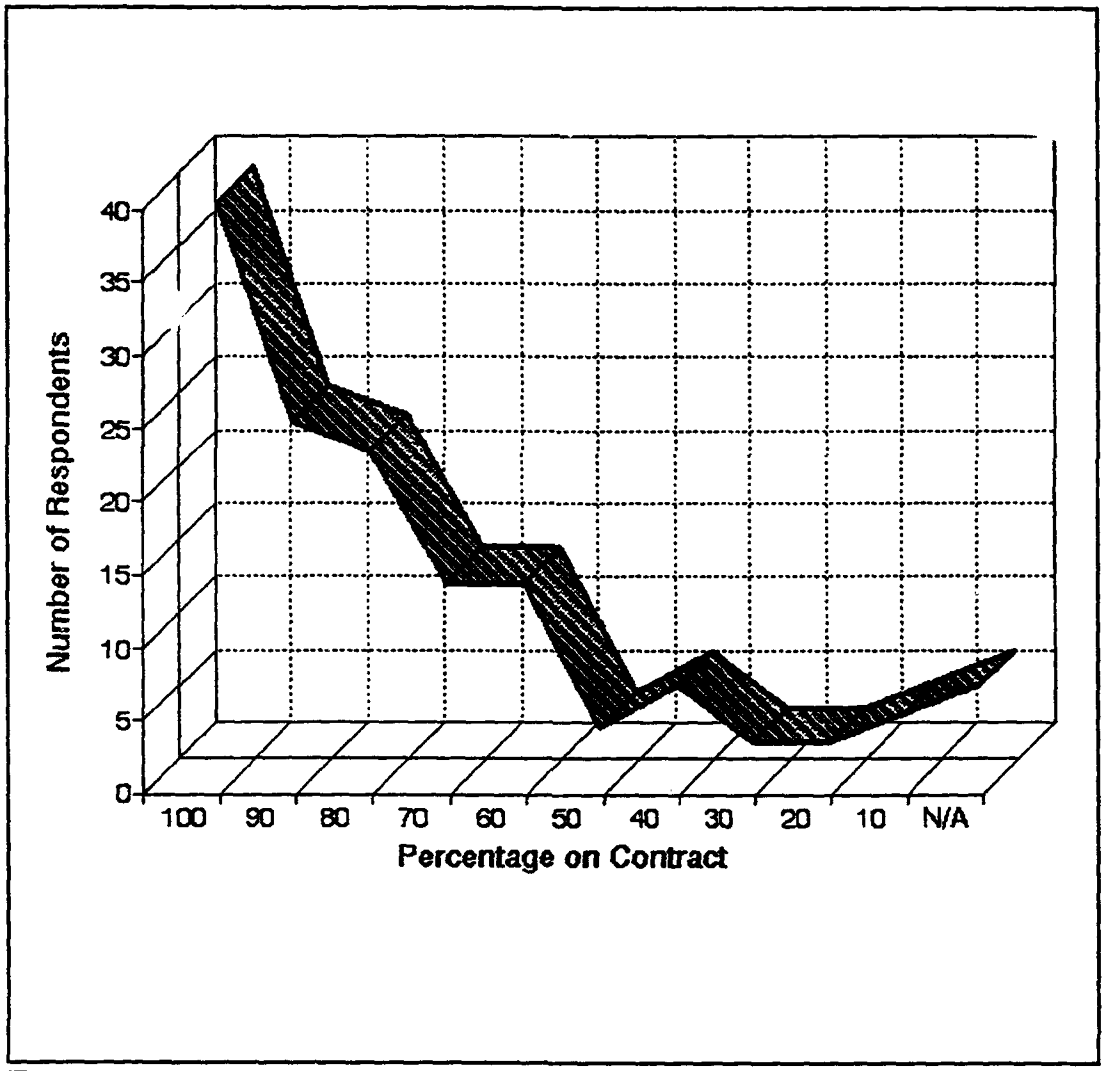


Figure 20. **Respondent Percentage by In-house Research**

4.2.k Discretionary Research One half the respondents indicated that less than 70 percent of their division's research was discretionary, or was not specifically requested by a SPO or outside organization (see Figure 21). Whatever the reason, this response distribution suggests that a formal R&D project selection tool might prove useful 70 percent of the time for at least half the people surveyed. This information will carry important implications as the research questions are explored and answered throughout the remainder of this chapter.

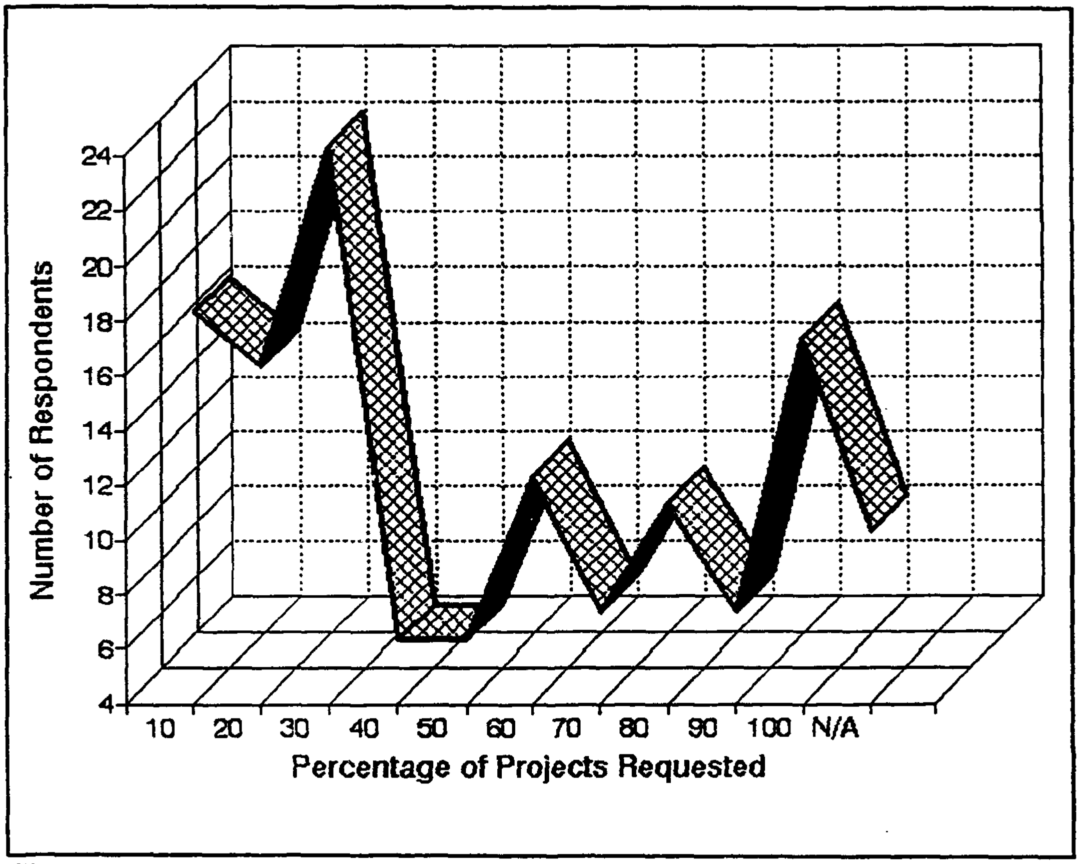


Figure 21. **Percentage of Discretionary Research**

4.2.1 Technique Awareness. Table 6 and Figure 22 summarize the tally from survey questions one through sixteen. These series of questions measured respondent familiarity with some accepted, formal R&D project selection techniques. It's readily apparent that over 50 percent of today's respondents professed literacy with at least three methods. Checklist, Cost/Benefit Ratio, and

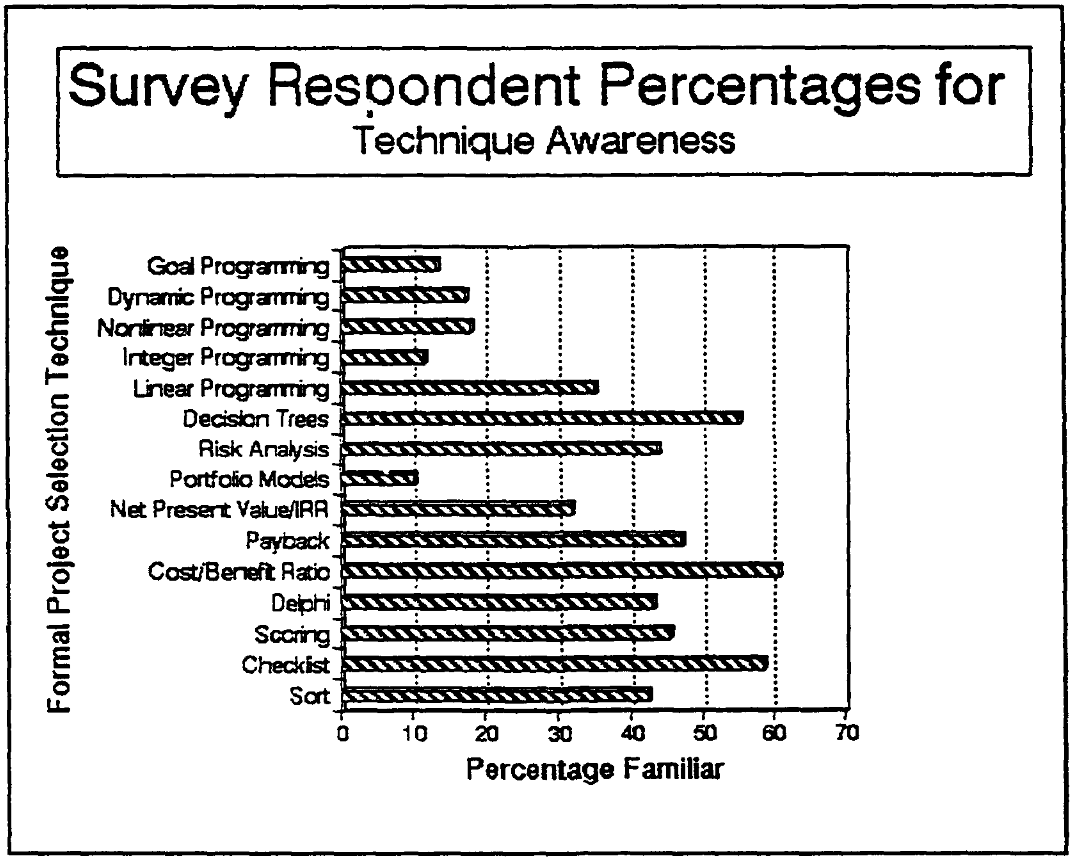


Figure 22. **Respondent Percentages for Technique Awareness**

Decision Tree techniques make up today's top three best-known methods for Wright Laboratory. Goal Programming, Integer Programming, and Portfolio Models all competed for the dubious distinction of "least-well-known" technique. One might presume a stronger prowess for Portfolio Models in a big laboratory

Familiarity with and Use of R&D Project Selection Techniques

Technique	Not Familiar (Percent)	Familiar (Percent)	Regular Use (Percent)
Q-Sort	57.81	42.19	14.84
Checklist	41.41	58.59	24.22
Scoring Models	54.69	45.31	19.53
Delphi	57.03	42.97	7.31
Cost/Benefit Ratio	39.06	60.94	13.28
Payback Period	53.13	46.87	7.81
Net Present Value /IRR	67.97	32.03	2.34
Portfolio Models	89.84	10.16	1.56
Risk Analysis/Monte Carlo	56.25	43.75	5.47
Decision Trees	44.53	55.47	10.94
Linear Programming	64.84	35.16	3.91
Integer Programming	88.28	11.72	.78
Nonlinear Programming	82.03	17.97	.78
Dynamic Programming	82.81	17.19	.78
Goal Programming	86.72	13.28	3.13

Table 6. **Technique Distributions for Awareness and Use**

environment, yet both the 1993 and 1988 results show equally low ratings for this method.

The top three techniques for 1993 reflect change from 1988 (see Figure 23). Please note that familiarity with the more "user friendly" techniques, like Sort and Checklist has grown at the expense of more rigorous methods like Risk Analysis, Linear Programming, Decision Tree and Delphi Methods. Prince noted this same

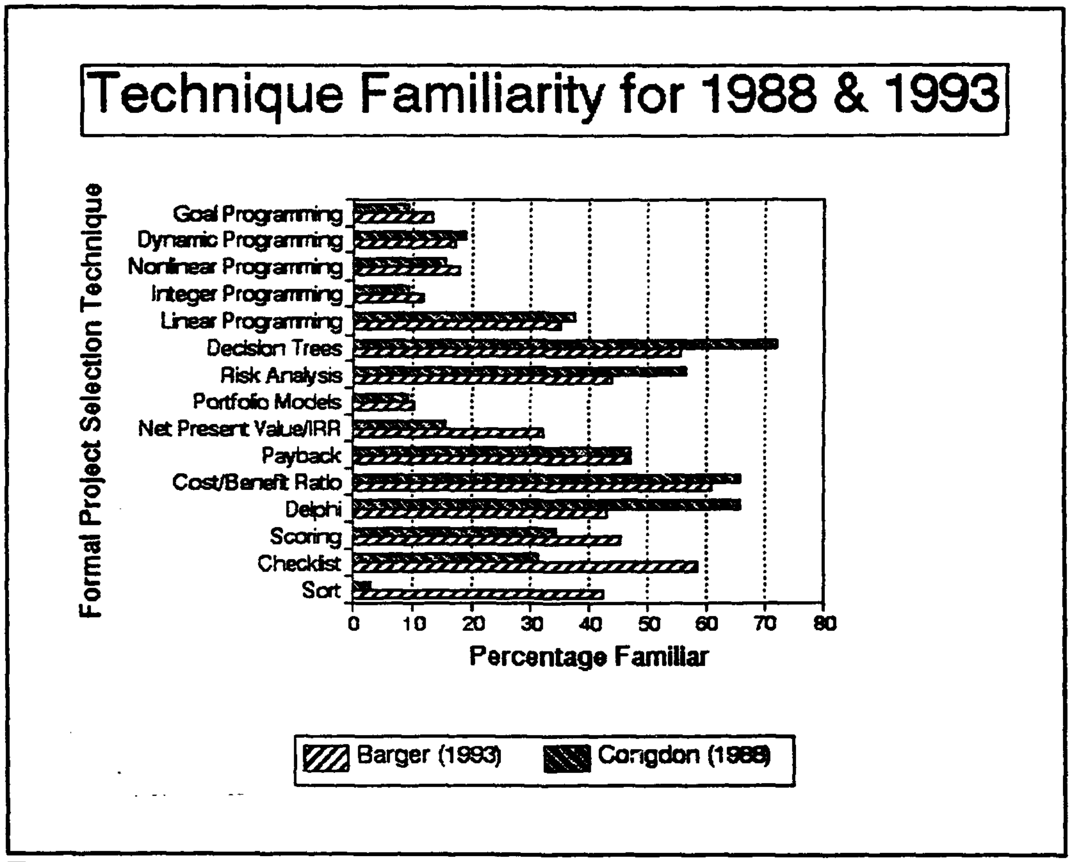


Figure 23. **Technique Familiarity for 1988 and 1993**

phenomena writing that the 1988 respondents used "relatively simple to learn and easy to use techniques" (Prince, 1988:38). Interestingly, respondent familiarity with Net Present Value and Internal Rate of Return has doubled since 1988 while

Cost/Benefit Ratio has dropped. Still nearly twice as many people remain familiar with Cost/Benefit Ratio today.

Most Wright Laboratory respondents describe Cost/Benefit Ratio as their best known technique. Does technique literacy, then, serve as a good predictor of a procedure's usefulness in a real decision making environment? Will the survey results show an overwhelming usage rate for the Cost/Benefit technique? Subsequent sections address this issue, prompting a surprising finding. The special emphasis on Cost/Benefit Ratio in this section, then, lays the groundwork for an important observation later on the subject of familiarity as a predictor value.

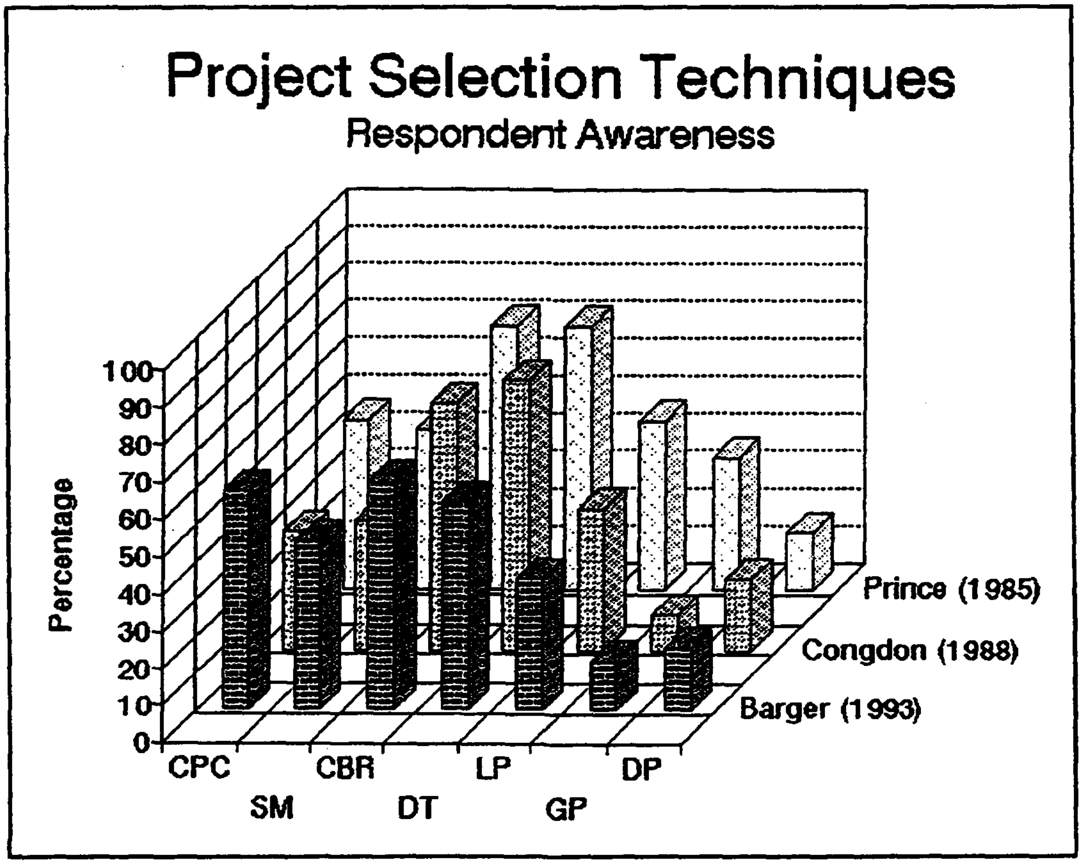


Figure 24. **Comparison of Awareness for 1985, 1988, 1993**

Congdon expressed concern at the low level of formal method familiarity considering the ratio of respondents completing Master's degrees (Congdon, 1988:62). Today's respondents exhibit higher educational levels with still lower total familiarity percentages. If Congdon's comments suggest an educational curriculum deficiency, then the educational system has facilitated little improvement in this statistic during the last one-half decade.

Figure 24 displays respondent familiarity on shared techniques surveyed in 1985, 1988 and 1993. The graph highlight's fluctuation through the years with many well documented methods, like Goal Programming.

4.3 Technique Use

Why were so many demographics collected and described in the preceding pages? Constructing a true picture of the laboratory hinges upon an accurate measurement of the distortions inherent in the research results collected through the years, using the differing methodologies and different survey samples. To the extent possible, differences in techniques springing from methodology or sample differences are identified.

Pie charts in Figures 25, 26, and 27, show formal methods usage, as a percentage of respondents, for three study years 1985, 1988, and 1993. Prince found 30 percent of the population employed a formal method in 1985. In 1988, only one in four of the personnel surveyed used a formal technique. Remembering the sample population differences between Prince and Congdon, one conceivable explanation for the statistic stems from the larger numbers of lower organizational participants used in 1988. However, maintaining this logic suggests that the 1993

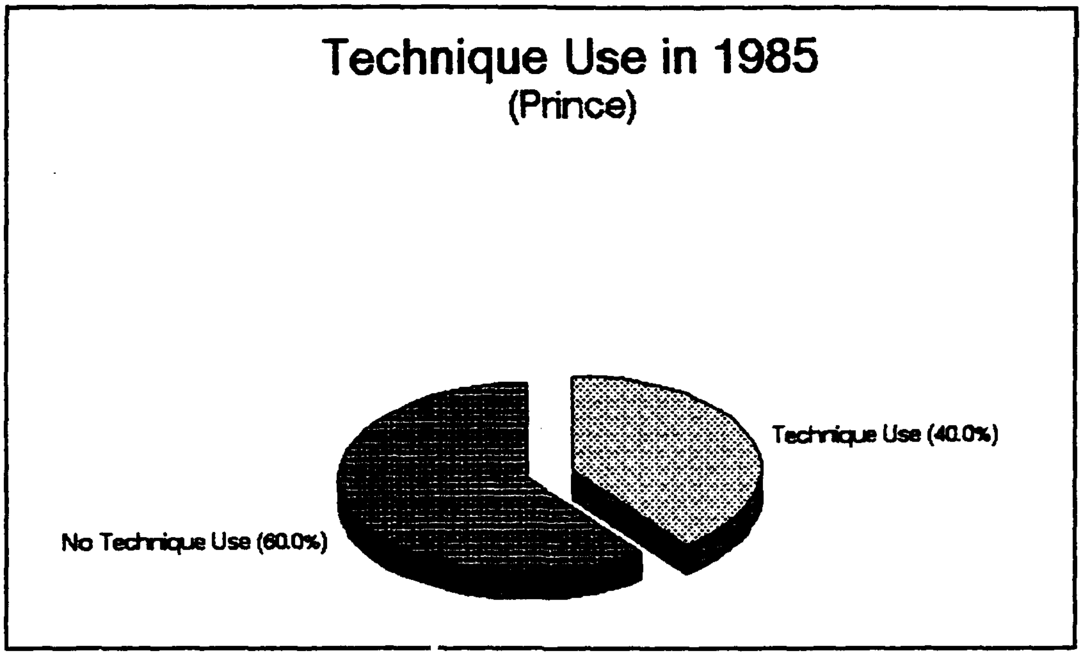


Figure 25. **Technique Use in 1985**

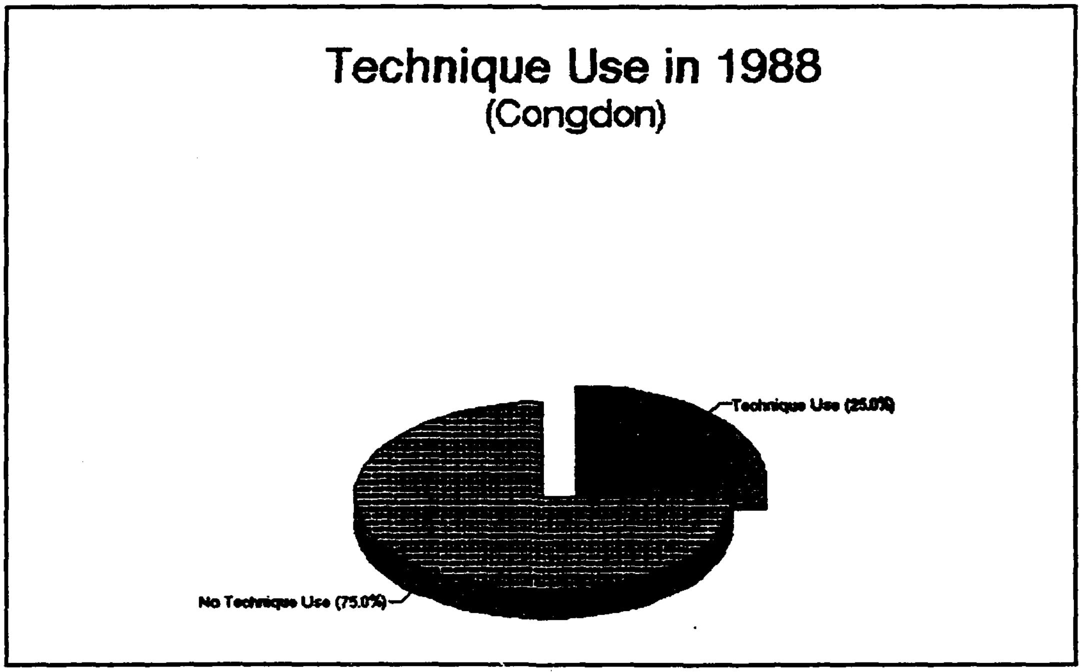


Figure 26. **Technique Use in 1988**

results should be lower still. Interestingly, nearly 50 percent of the 1993 respondents, when asked if they used a technique, responded positively. The 1993 results show nearly a two-fold growth in just five years. This statistic offers a surprise since today's respondents typically include workers at lower organizational levels.

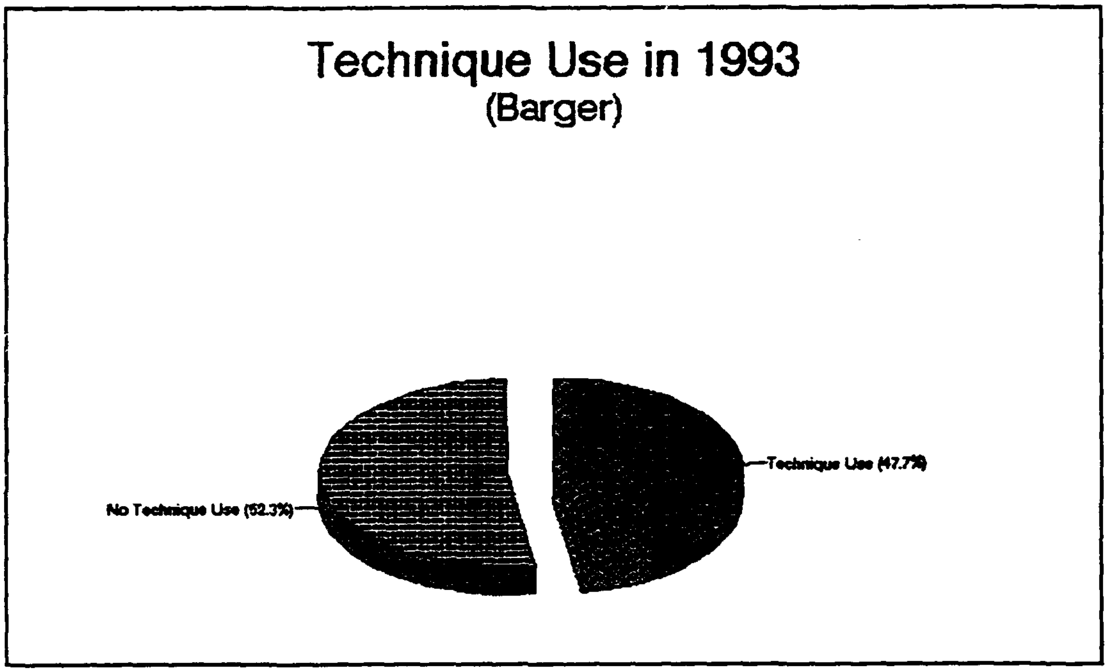


Figure 27. **Technique Use in 1993**

Further, these same respondents have expressed lower total familiarity with the various decision-making methods available.

The distribution of respondents using formal methods when grouped by organizational level manifests an almost linear relationship between percentage use and hierarchical position (see Figure 28). The "directorate level" personnel exhibit twice the likelihood of using a formal method as Wright Laboratory's "section level" personnel. Indeed, many would argue that personnel at the section level should focus on research and not decision-making. Unfortunately, this view does not consider a formal techniques' applicability to an individual's routine decision-making process.

In clear contrast to the linear relationships displayed across laboratory hierarchy, there exists substantial diversity in usage percentages between directorates (see Figure 29). As one might expect, the Plans & Programs Directorate

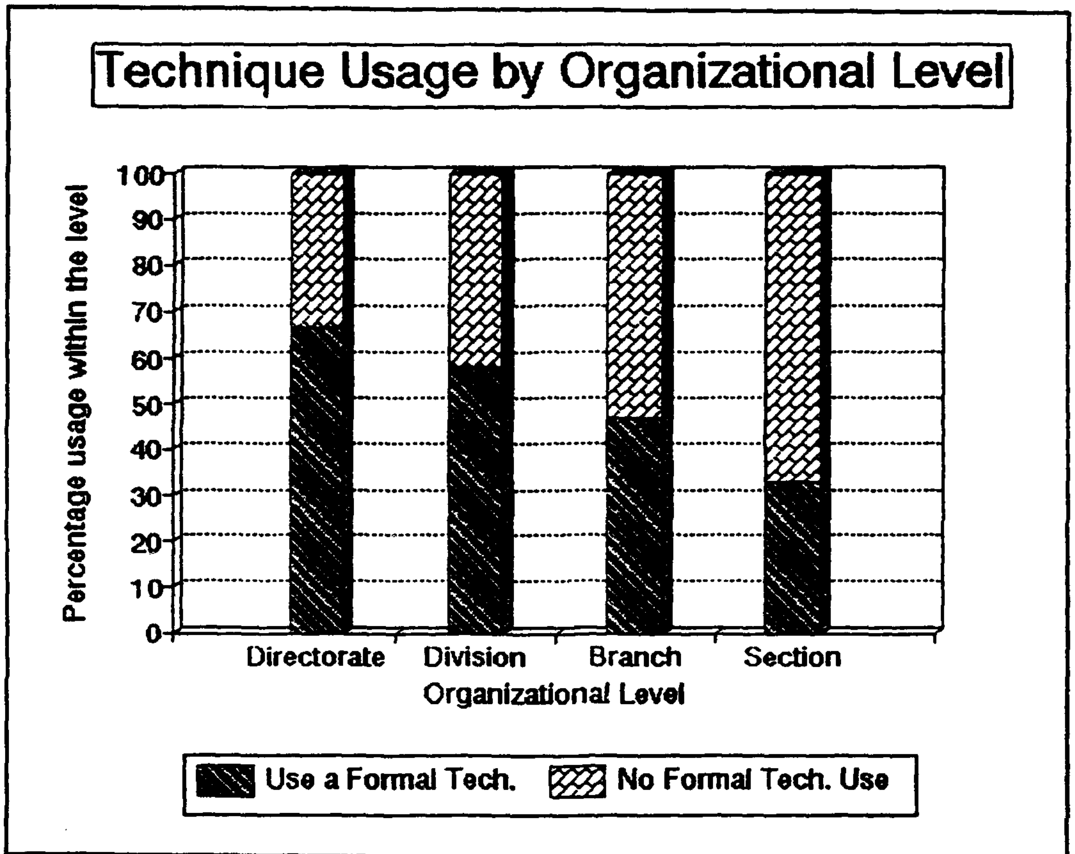


Figure 28. **Technique Usage by Organizational Level**

exhibits a high usage propensity. The directorate's small size contrasts with its enormous task, plotting the laboratory's course through the 20th century's high technology frontier. However, the Plans & Programs Directorate's task lends itself well to formal technique usage. Within the Wright Laboratory directorates as a whole, great gulfs abide in technique application. For example, Materials Directorate's formal technique usage far outstrips either Armament or Solid State Electronics Directorate's application levels.

A statistical procedure was used to test for a diversity in usage phenomena. The small sample size of six respondents in one directorate coupled with an unknown potential for normal data distribution overall made the Kruskal-Wallis test appropriate. Acceptance of the null hypothesis occurred if usage levels were statistically identical at an alpha level of 0.10. This test supported the alternate

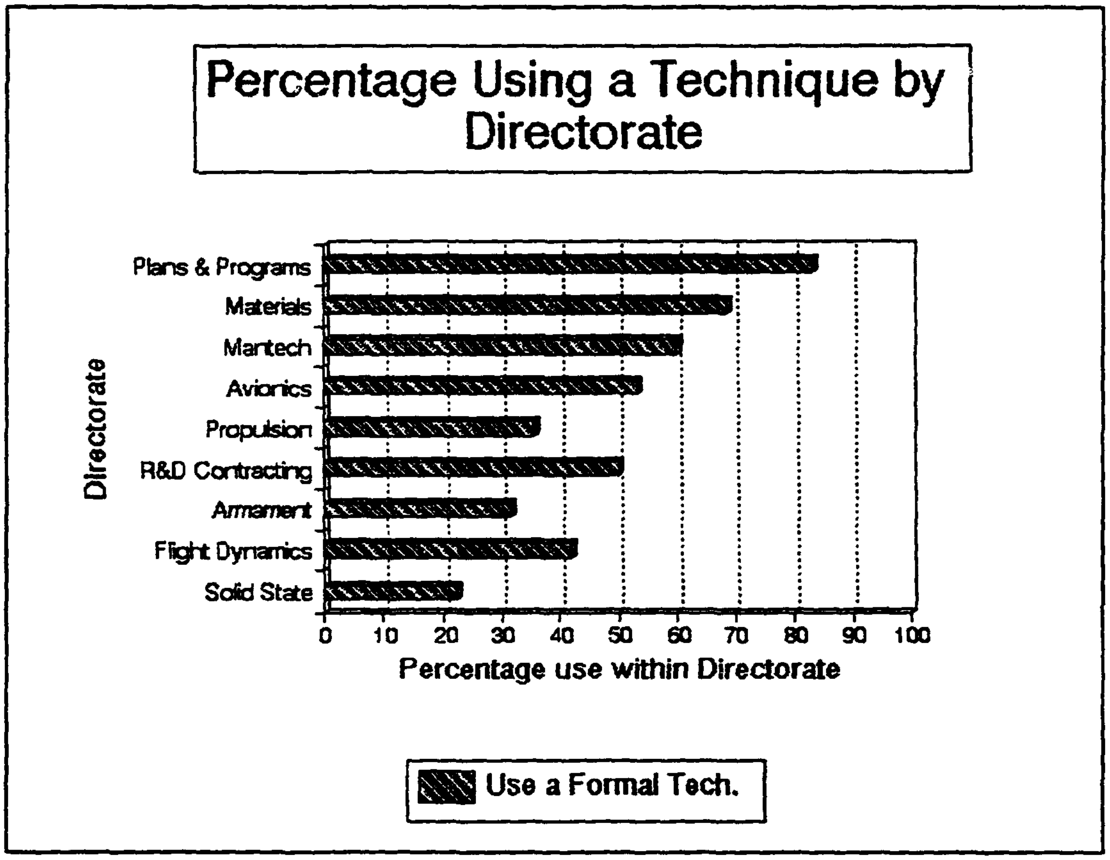


Figure 29. **Percentage Using Technique by Directorate**

hypothesis that usage levels across directorates were *not* the same. An X^2 value of 12.4 exceeded the test statistic of 12.02, at seven degrees of freedom, with a p-value of .09. One concludes, then, that at least two of the eight directorates tested, wielded formal techniques differently. These statistical results appear reasonably concrete, but one need only study the following graphs to intuitively confirm the mathematics.

Individual Directorates' supporting or opposing rationale for formal meth-od(s) use lay beyond this research effort's domain. Yet, the survey data clearly show that, whatever the reasons for using or not employing a formal decision method, technique knowledge *does not*, necessarily, propitiate technique use. The Solid State Electronics Directorate serves as an example in this query. Their responses suggested they were cognizant of many formal techniques. Fifty percent of the respondents recorded familiarity with the cost/benefit ratio technique. In fact, many were conversant with other methods as well. Yet, no one used the cost/benefit method in the directorate. However, the following caution is in order: failure to use a particular technique is not the issue here. The driving issue is whether there is an unknown potential(s) for any one, or many, formal technique(s) to be inappropriate in a given application. It appears that the cost/benefit technique is not an effective method for Solid State Electronics directorate. Building on this thought, while realizing that Wright Laboratory exhibits strong knowledge and usage levels for formal techniques, one can question if the organization feels that any or all techniques lend themselves to laboratory use. In the case of the Solid State Electronics directorate, perhaps the cost/benefit technique does not easily adapt itself to their decision conditions.

A Wilcoxon rank sum test was used to probe for disagreement on this issue within Wright Laboratory. The null hypothesis that the directorates agreed in their opinion on likelihood that a formal project selection technique which would be useful during project selection and resource allocation could be developed, was supported. The Kruskal-Wallis test (Chi-Square Approximation) was 7.4834 with seven degrees of freedom and p=.38. Therefore, the directorates appear to be in agreement on the issue. Interestingly, the Kruskal-Wallis test confirmed a directorate agreement that the likelihood of a technique being developed was "uncertain." However, Solid State Electronics respondents were more pessimistic, deeming the likelihood as closer to "unlikely!" Their mean score was the largest of all compared on this issue.

These statistics suggest the directorates are uncertain if a formal method can be developed to meet all their needs. However, they do employ some well-known formal techniques as appropriate. Further, as subsequent sections show, the directorates employ the myriad of techniques to dissimilar degrees.

Comparing the survey results for technique usage by age revealed non-use by the younger respondents between 20-25 (see Figure 30). However, the low number of responses, only 7 percent, for population between the age span between 20 and 30 imparts low reliability to this measure. After age 25, technique usage increases through age 40. Between ages 40 and 50 application tapers off to levels of less than 30 percent, but rebounds to higher levels prior to age 55.

Statistics on formal technique usage by military rank reveals that Captain through Lieutenant Colonel rank's advocate technique usage more than Colonels (see Figure 31). Again, the low numbers of respondents, six people in the Lieutenant and Colonel ranks, give this measure questionable merit. In the mid ranges the data provides a higher reliability and becomes more indicative of the population. The civilian grades exhibited less percentage of use at the upper tier when GS and GM categories are combined, but again the statistical reliability suffers because of few respondents at these higher levels (see Figure 32).

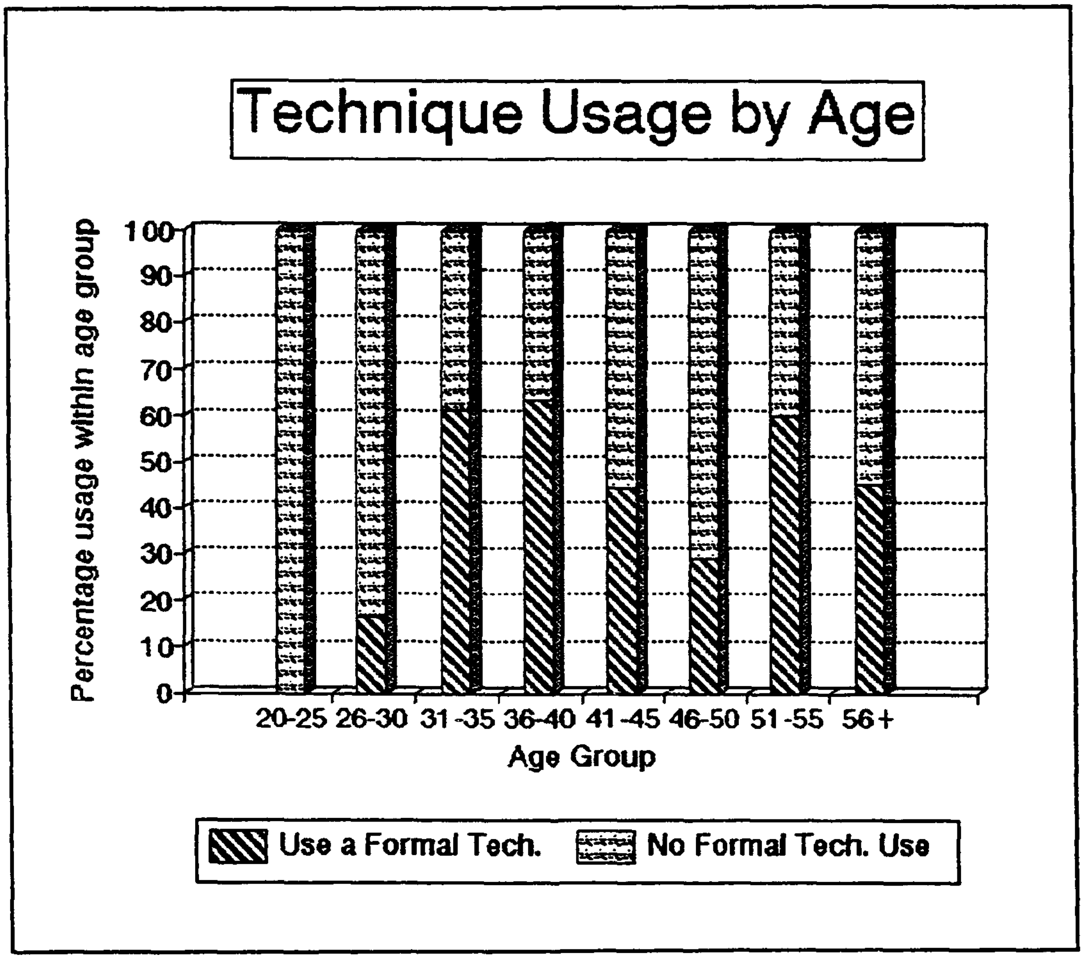


Figure 30. **Technique Usage by Age**

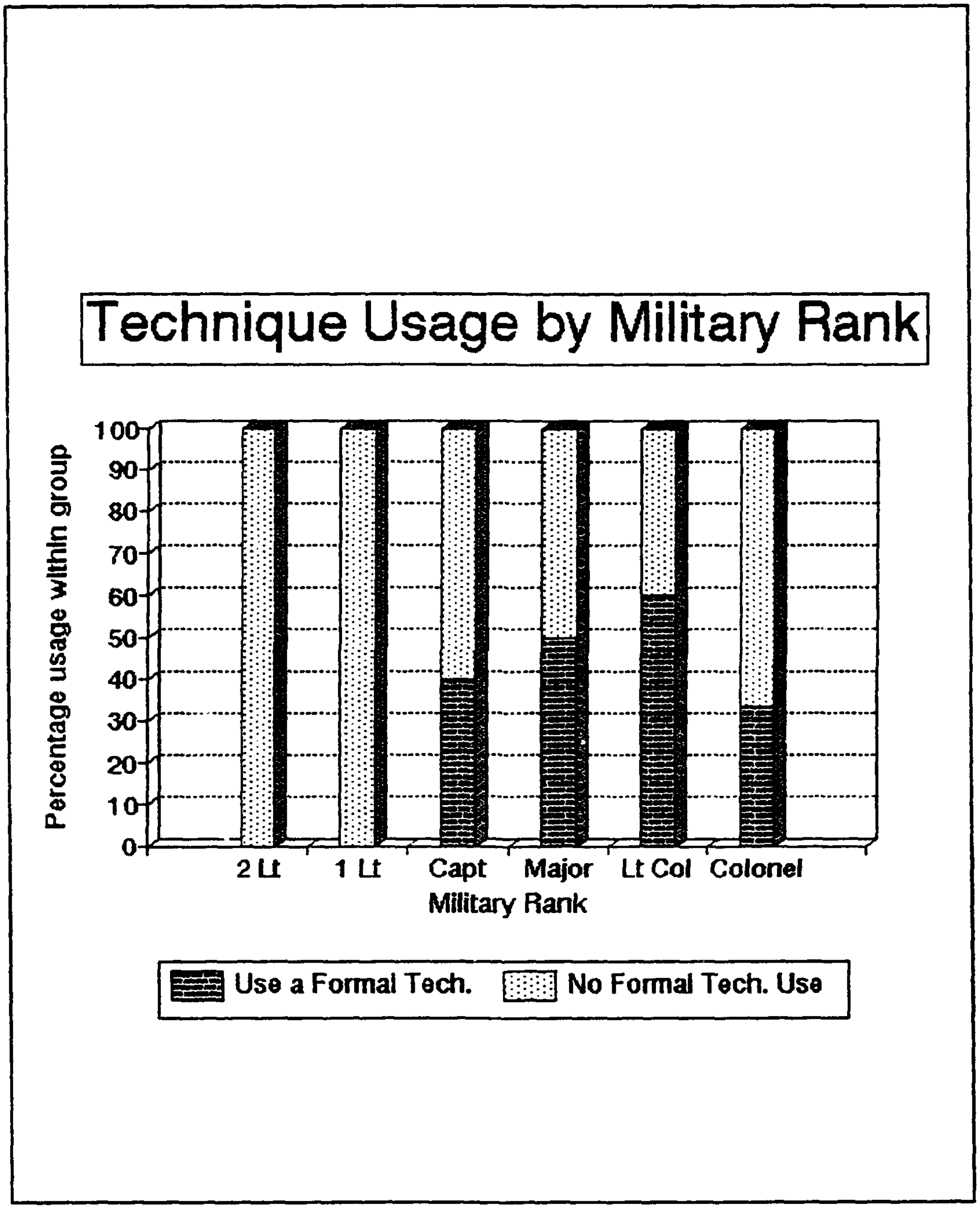


Figure 31. **Technique Usage by Rank**

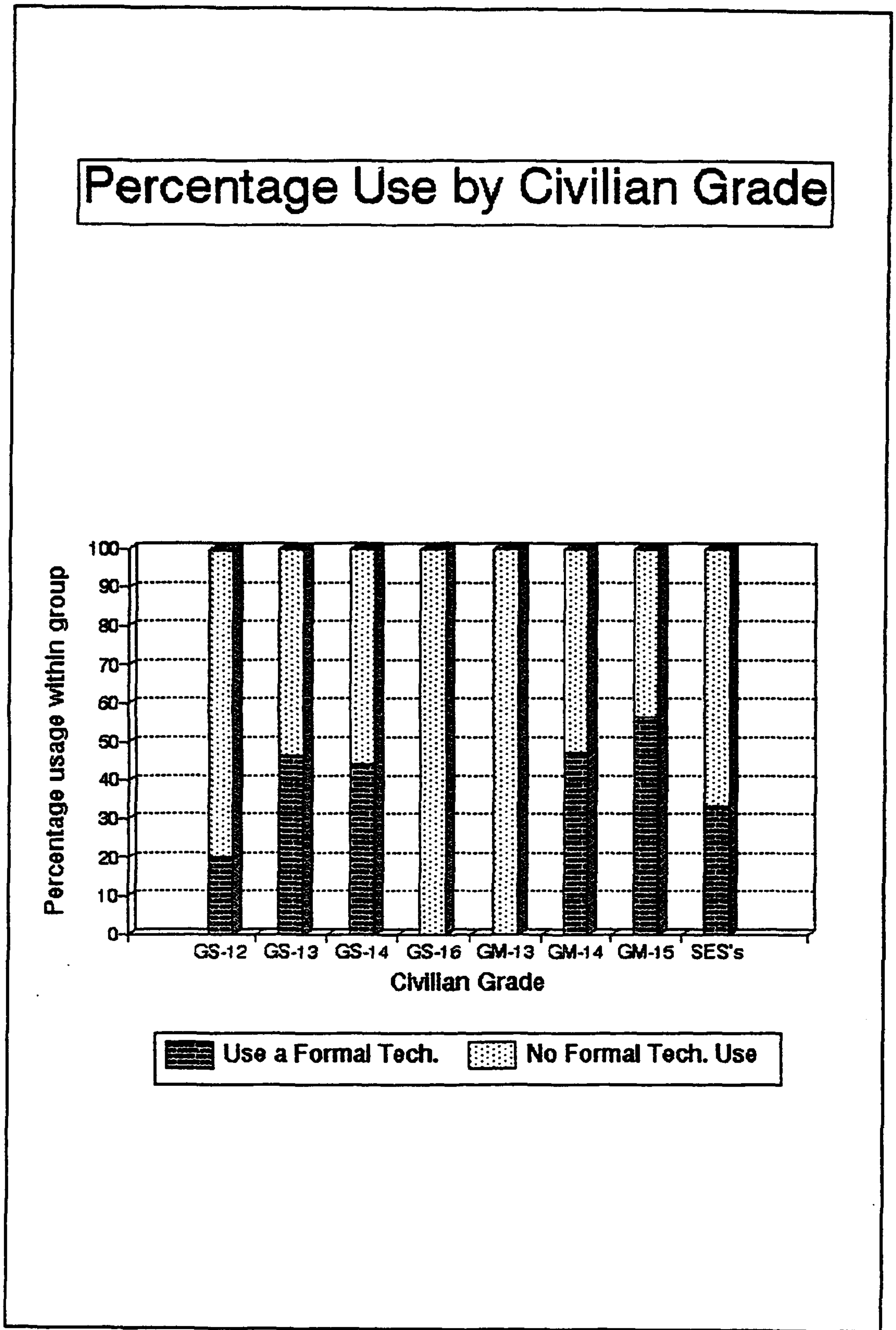


Figure 32. **Percentage Use by Civilian Grade**

A ribbon chart in Figure 33 confirms that the probability of formal technique usage in a decision process strides to 100 percent as the budget involved

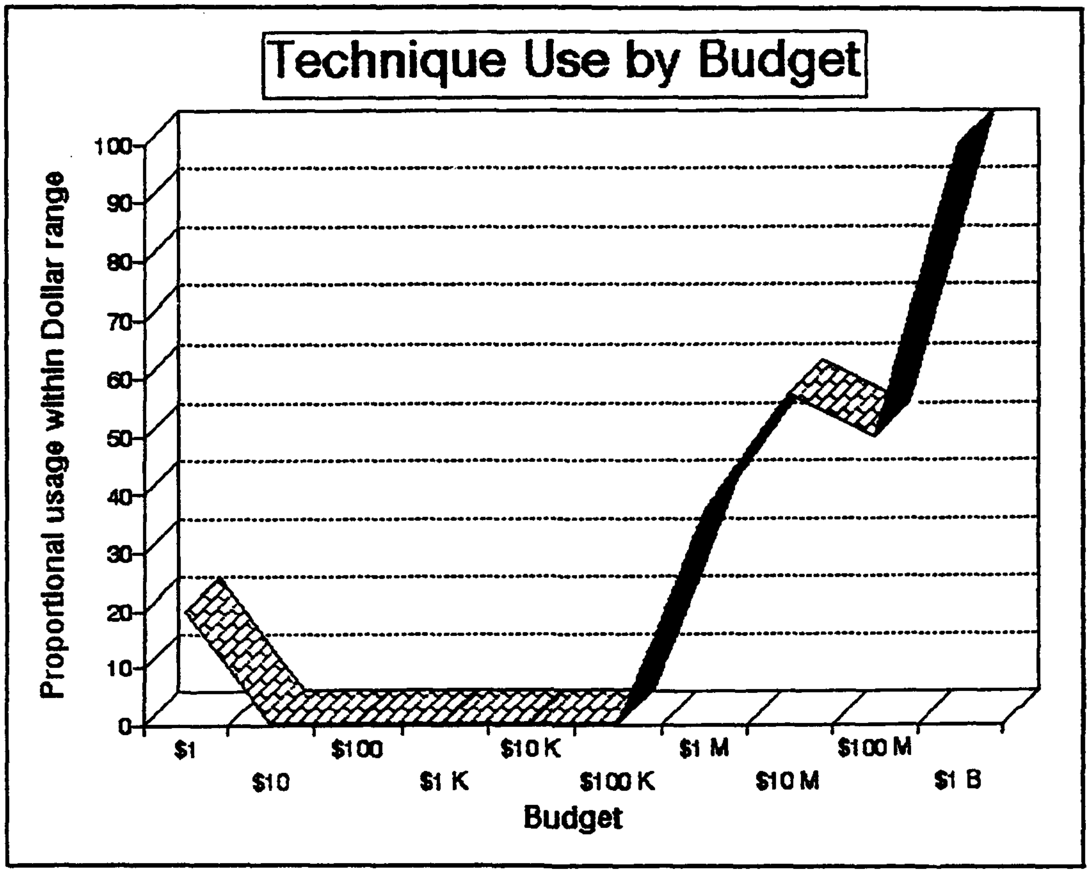


Figure 33. **Technique Usage by Budget**

approaches $1 Billion. However at lower dollar ranges, formal techniques can function in roles other than monetary resolution. Some of these roles are examined in the next section. A deeper discussion of published decision making techniques' strengths, weaknesses, and authoritative references appear in Appendix B. Jordan's Naval Postgraduate thesis provides an additional information source. He wrote from the military managers' perspective (Jordan, 1992).

4.4 Question 1: Project Selection Methods

What methods do managers use to select R&D projects and allocate laboratory resources at Wright Laboratory?

The previous section established that technique usage varied between directorates. Additionally, individual directorates embraced different combinations of methodologies. For example, the Plans & Programs Directorate clearly preferred the checklist technique. Aerospace Propulsion & Power Directorate, on the other

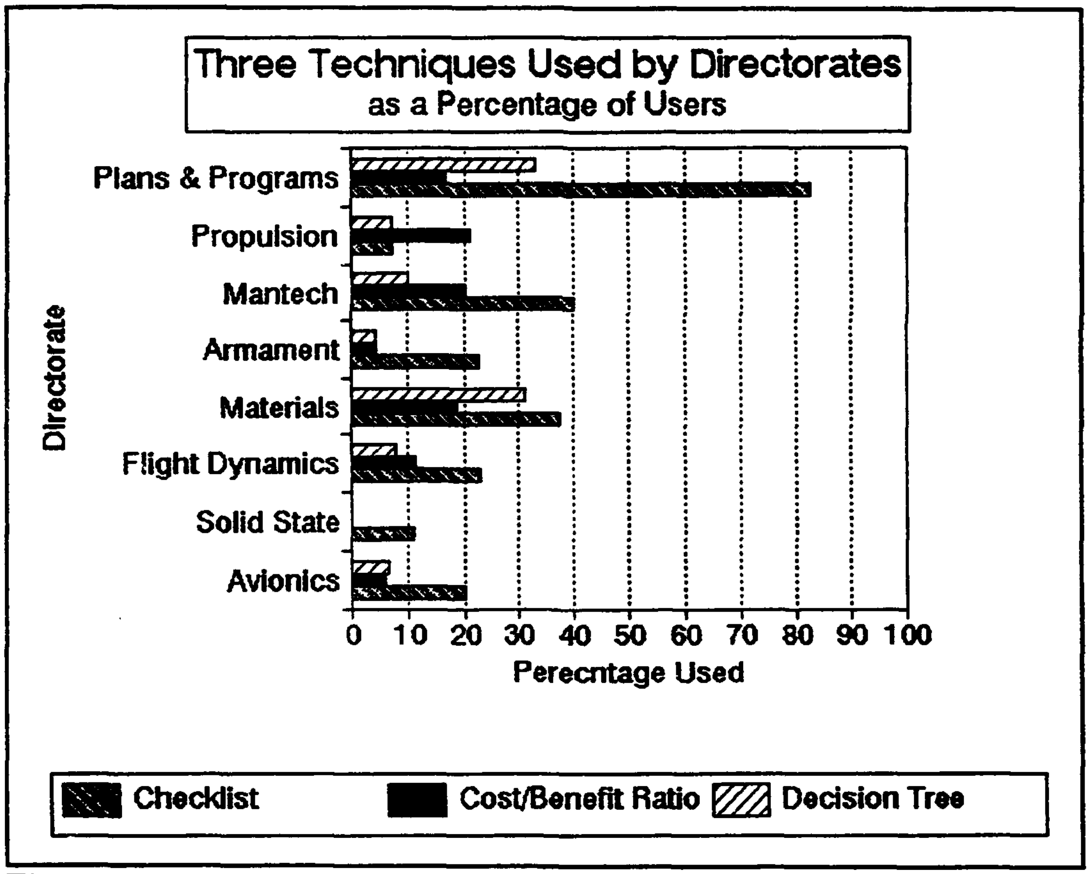
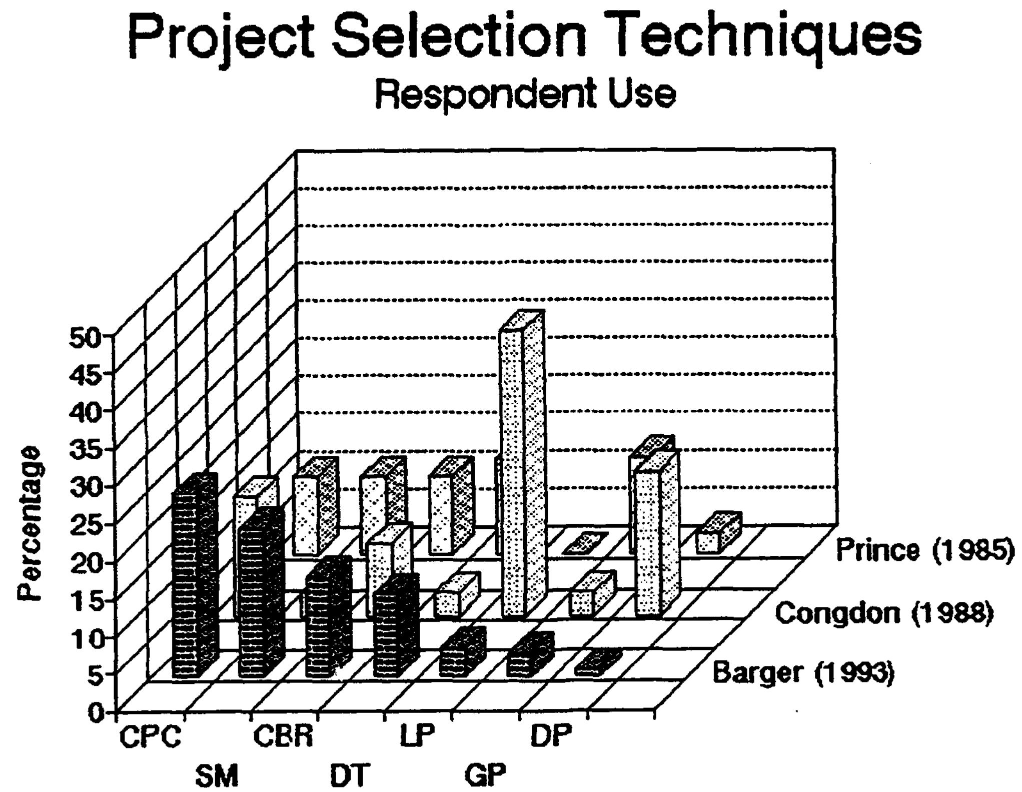


Figure 34. Comparison of Three Techniques Used by Directorates

hand, applied cost/benefit ratio two-to-one over other techniques. Figure 34 compares three formal methods used across the directorates. The evidence suggests that Wright Laboratory directorates exhibit a propensity to style unique combinations of decision-making methods to cope with their distinctive decision climate.

A bar chart (see Figure 35), displaying some common techniques among three studies, shows usage pattern fluctuation among the years. The metamorphosis of routines employed hint of adaptive decision-making on a macro scale.



Acronyms:

CPC	Checklist and Profile Charts
SM	Scoring Models
CBR	Cost/Benefit Ratio
DT	Decision Trees
LP	Linear Programming
GP	Goal Programming
DP	Dynamic Programming

Figure 35. **Technique Used for 1985, 1988, 1993**

For example, Prince found great support for goal programming in 1985. By 1988 the technique had fallen from popularity while linear programming use skyrocketed. Then, in 1993, linear programming use plummeted back to a peer plane with goal programming. Other charts displayed throughout the subsequent pages (see Figures 36-43) detail the unique mix of methods employed by directorate. However, the reader is cautioned that any comparison between 1985, 1988, and 1993 should consider the differences in the sample populations surveyed.

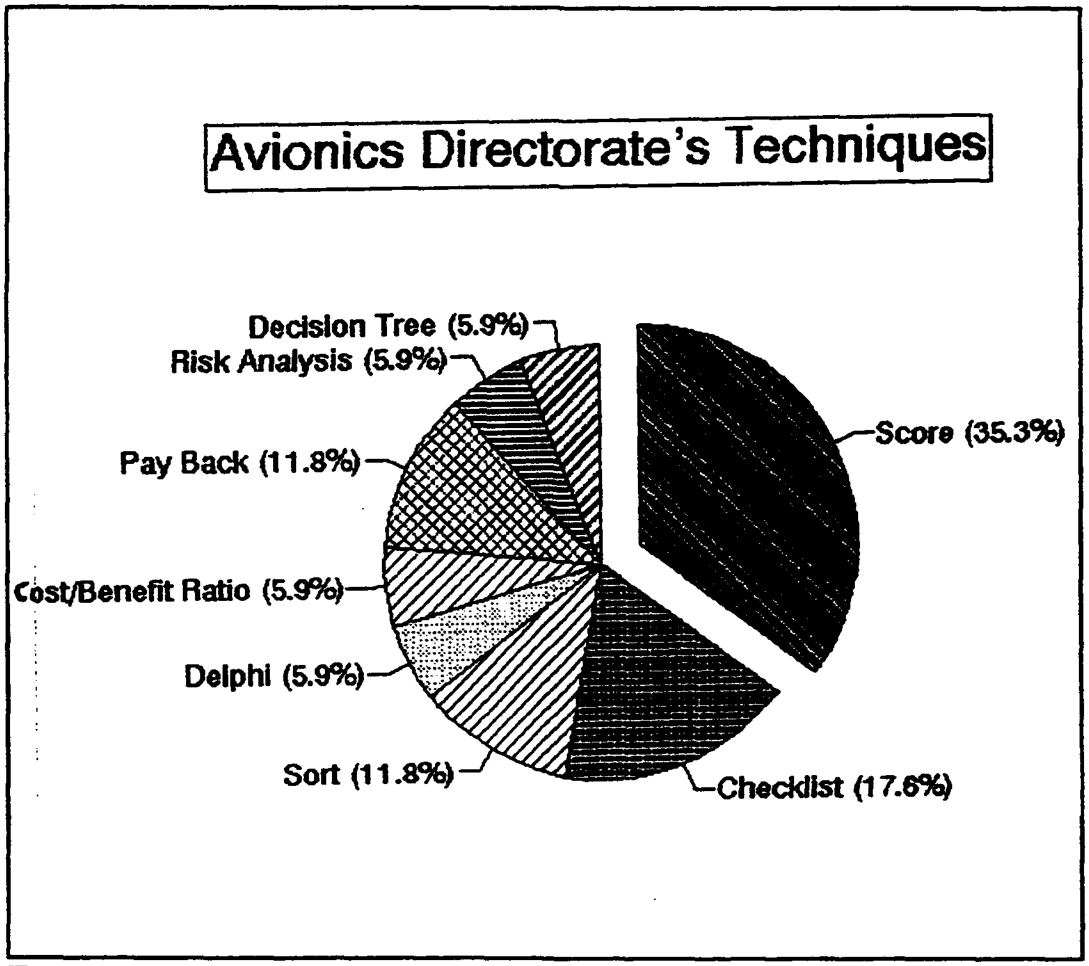


Figure 36. **Methods Used in Avionics**

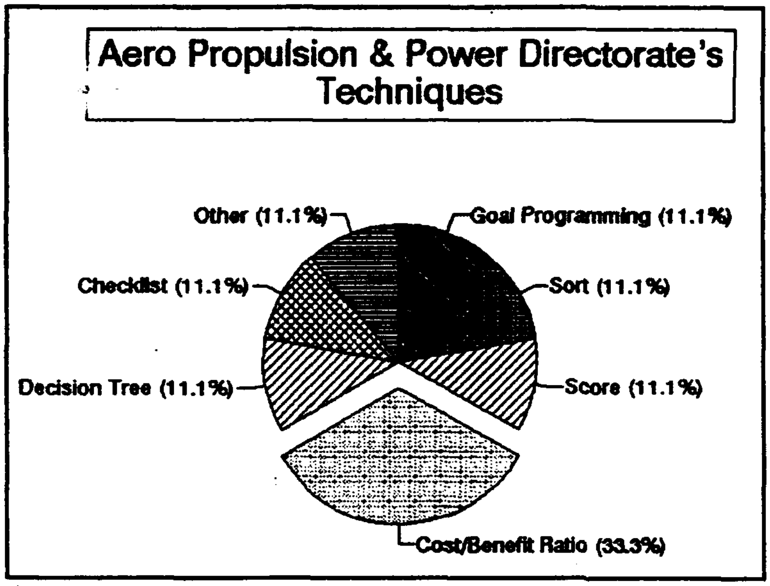


Figure 37. **Methods Used in Aero Propulsion & Power**

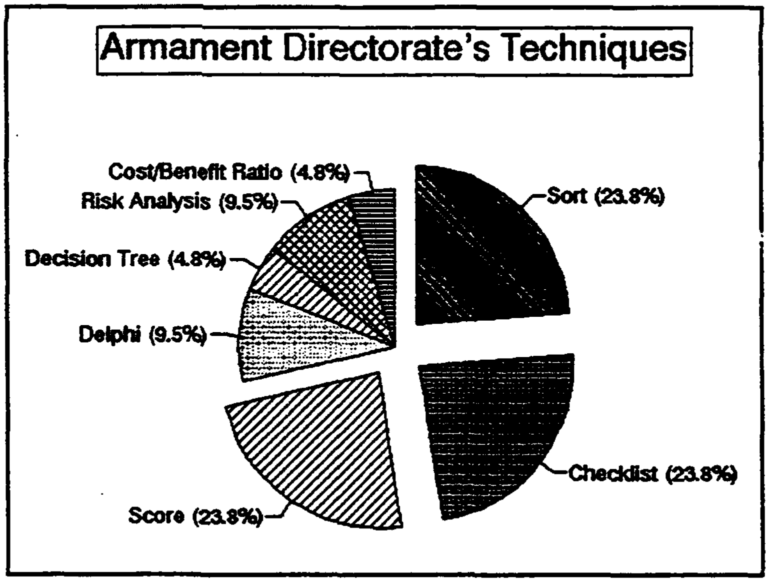


Figure 38. **Methods Used in Armament**

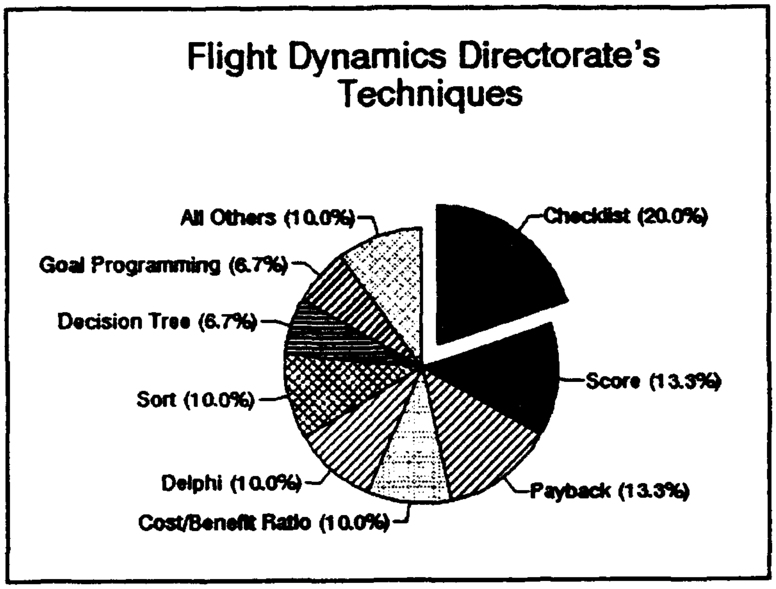


Figure 39. **Methods Used in Flight Dynamics**

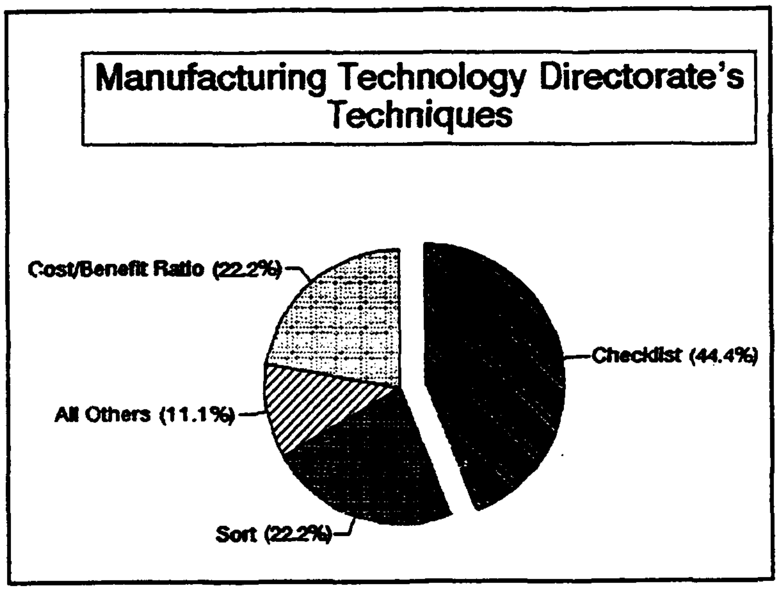


Figure 40. **Methods Used in Manufacturing Technology**

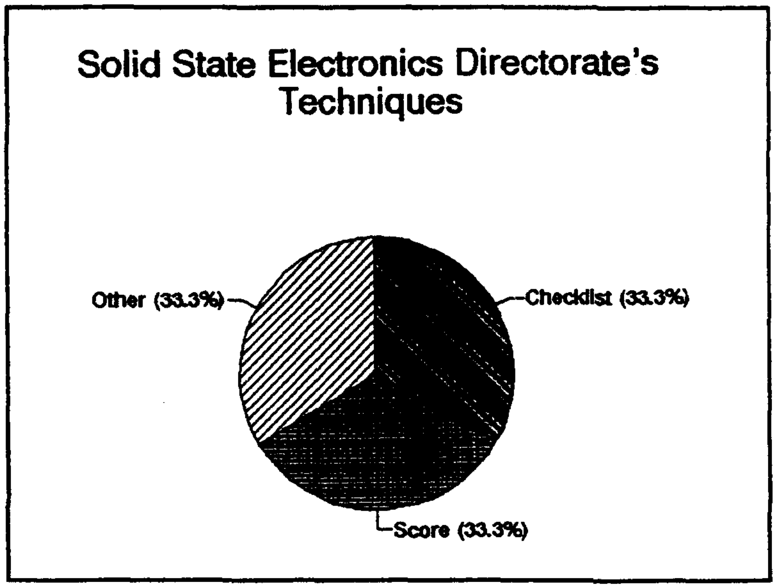


Figure 41. **Methods Used in Solid State Electronics**

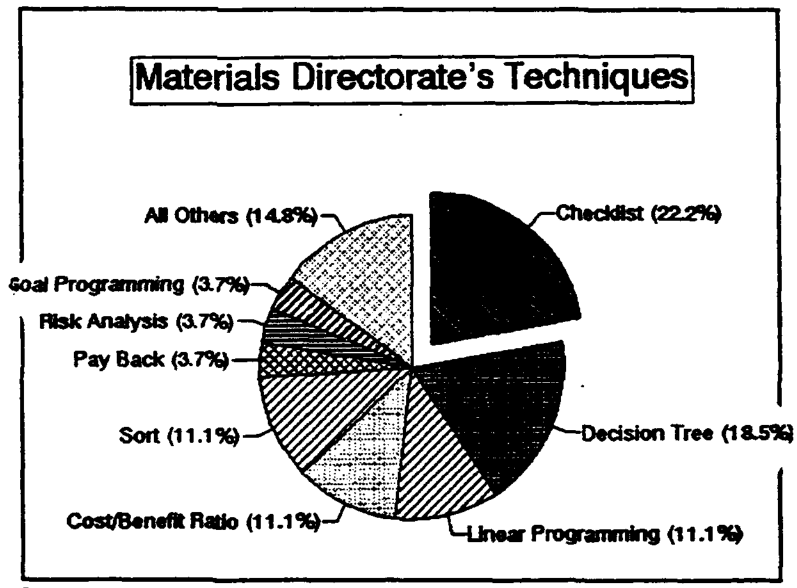


Figure 42. **Methods Used in Materials**

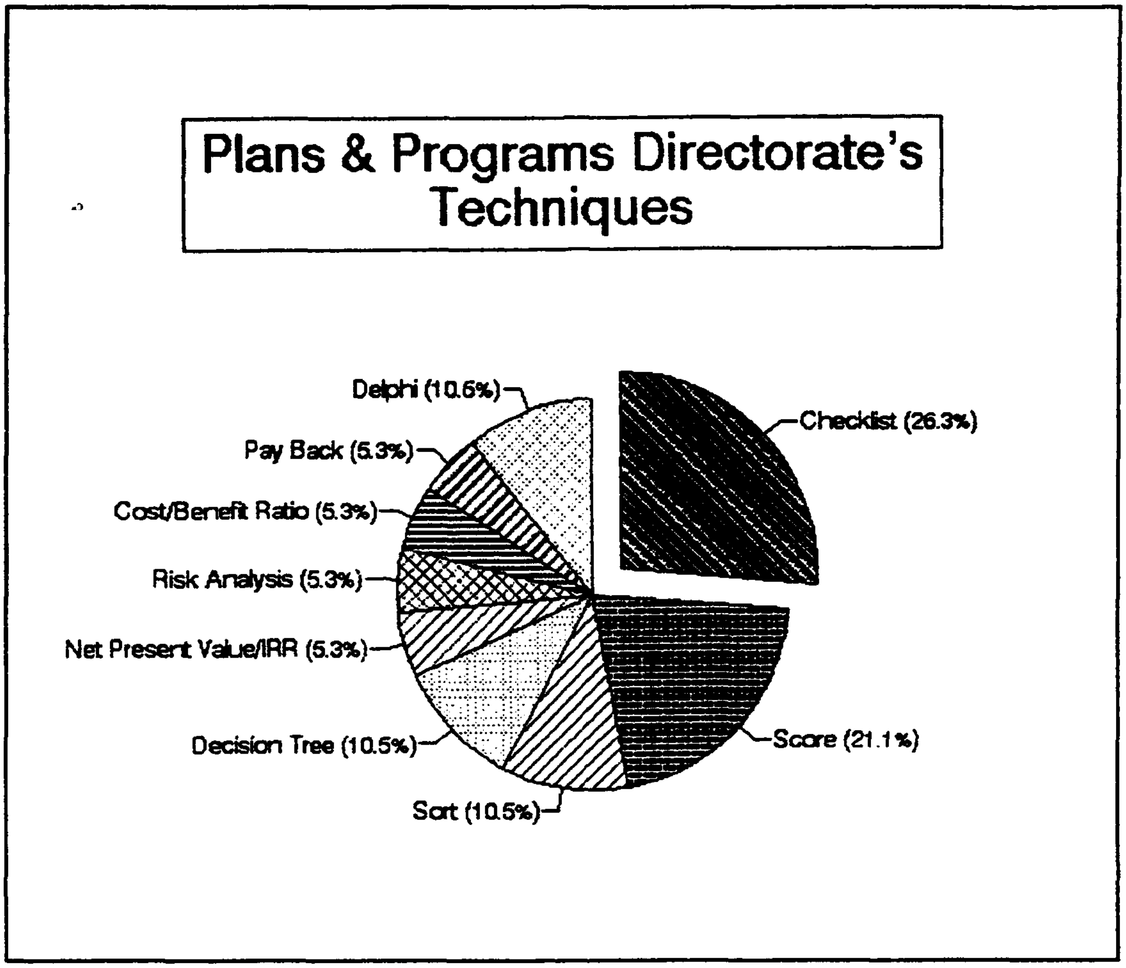


Figure 43. **Methods Used in Plans & Programs**

Throughout the preceding pages and sections, graph after graph describes the fluctuating and constantly transforming decision-making process within Wright Laboratory. The statistics also describe an organization familiar with many formal techniques. Clearly, Wright Laboratory regularly exercises numerous formal techniques, while others, despite being well understood, are discarded. The graphs reflect a large laboratory organization adapting technique usage through the years and across the organizational structure to meet its decision making environment. Undoubtedly, Wright Laboratory does not blindly enforce an ill-fitted application, nor does it employ a technique simple because it is well known throughout the organization.

4.5 Question 2: Lateral Airfoil Research Validity

What establishes lateral airfoils as a potentially viable research project?

Recall that Section 2.5 addressed this question from a bibliometric approach. The narrative compared many patents granted for aerospace vehicle designs and described lateral airfoil applications for gas turbine engines and naval propulsion systems. The information presented within Chapter 2 met the intent of this research question. However, in a further test of lateral airfoil research potential, each of the thirty-six interview participants was asked if they would: 1) Support a lateral airfoil research project; 2) Table the project until some later date; or 3) Oppose the project. The decision makers marked their response after hearing a short, 5-7 minute, overview of the aerospace vehicle design. The participants' information

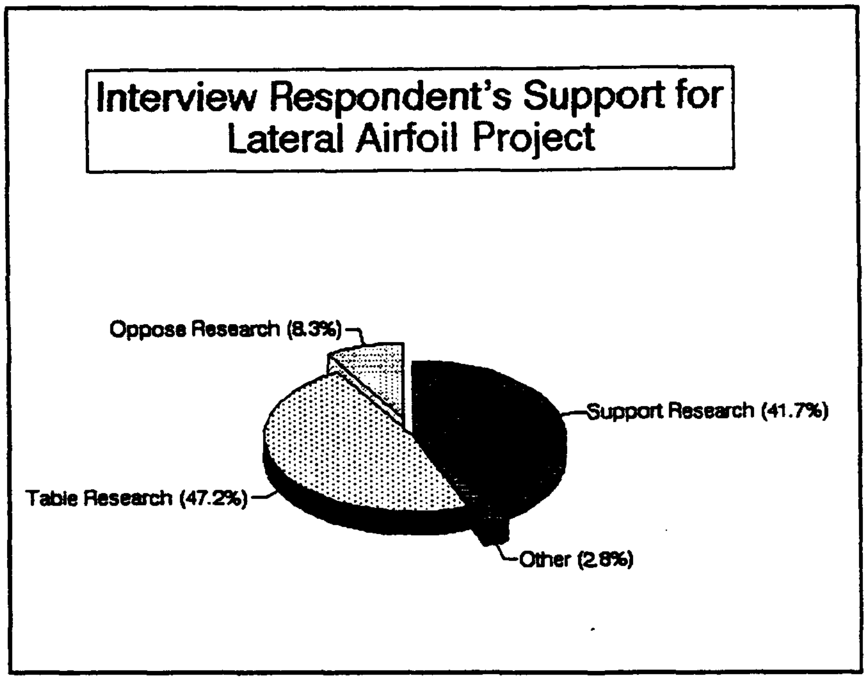


Figure 44. **Interview Respondent's Support for Lateral Airfoil Project**

included an engineering development cost estimate of $210 million. This procedure minimized interview time and placed each respondent at about the same level of disadvantage on lateral airfoils.

When asked, only 8 percent of the 36 participants truly opposed the project (see Figure 44). However, almost all participants verbally predicated their support upon receiving positive answers to the decision criteria that they subsequently listed and evaluated on the interview guide. For example, more than one individual wanted to know if any basic research had been performed and if so, was that prior research successful enough to merit further lateral airfoil development. These results support the use of lateral airfoil technology in answering Research Questions 3 and 4.

4.6 Question 3: Determinant Attributes Used

What determinant attributes do decision makers use in a final choice set during research program portfolio selection?

The reader may recall the discussion earlier of Doctors Stahl and Harrell who conducted interviews with Wright Laboratory personnel in the late 1970's. They found six predictive factors (determinant attributes) commonly used in the decision making environment (see Figure 45). They talked with personnel from the command section through section chief levels. Generally, once the determinant attributes or predictor criteria are known, other researchers can design experiments to model the decision making process. Brooks subsequently used Stahl and Harrell's determinant attributes to develop a model of Wright Laboratory's decision making process (Brooks, 1979:51). He found that all six factors identified by Stahl

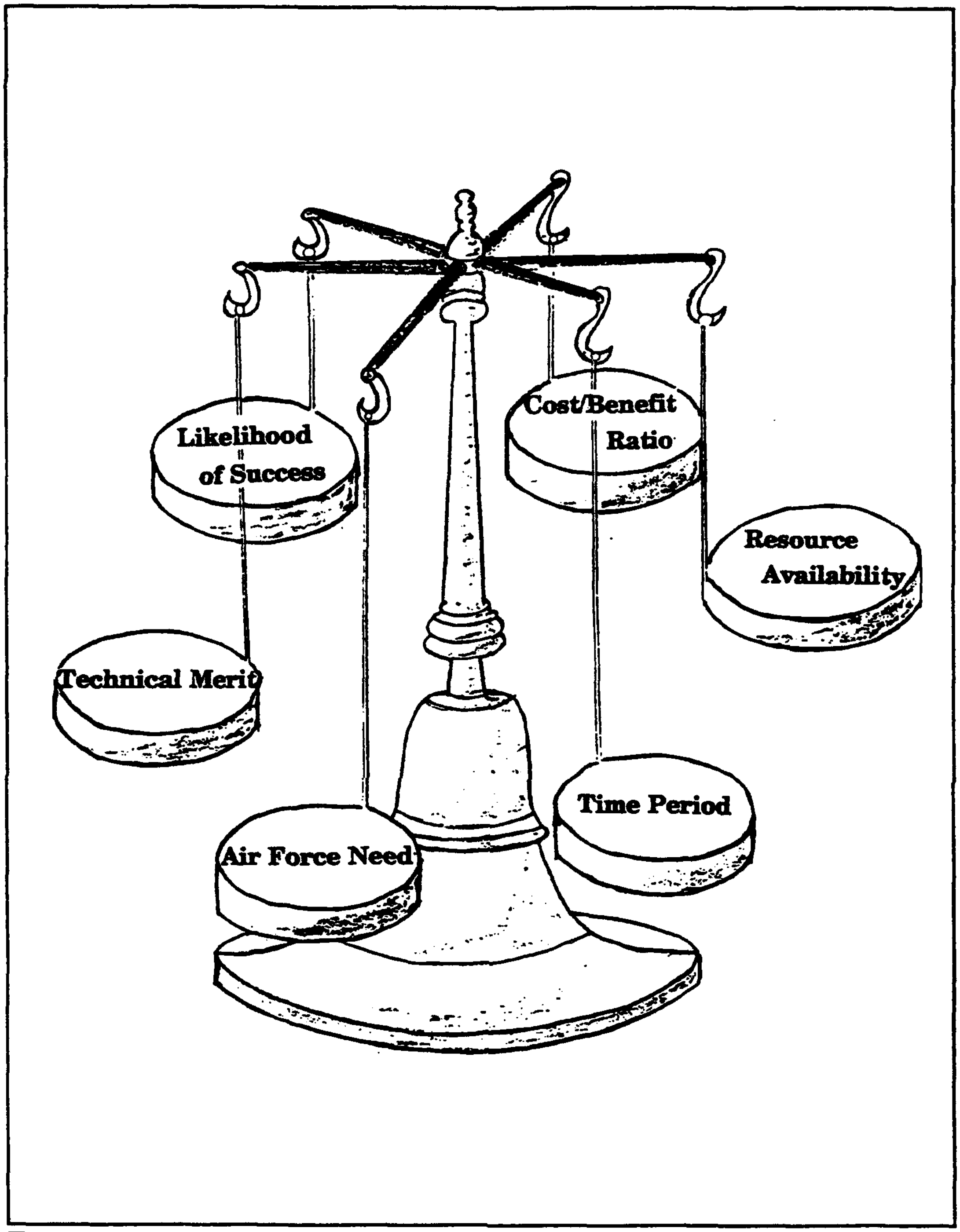


Figure 45. **Stahl and Harrell's Determinant Attributes (Brooks, 1979)**

and Harrell combined to form a linear model accurately describing Wright Laboratory decision making process of the late 1970's. The six attributes ranked by order of Brooks' research beta weights are:

1. ***Air Force Need***
2. ***Technical Merit***
3. ***Cost/Benefit Ratio***
4. ***Resource Availability***
5. ***Likelihood of Success***
6. ***Time Period.***

(Brooks, 19[illegible]:73-4)

Unfortunately, no documentation exists explaining how Stahl or Harrell identified these criteria. Therefore, the 1993 research process targeted this material void, successfully identifying a greatly expanded set of criteria. Additionally the same criteria advocated by Stahl and Harrell were reintroduced to gauge their merit for today.

The 1993 results distilled from the interview process where each participant was asked to list and measure the utility of their decision criteria in a lateral airfoil research project decision. Approximately sixty distinctive criteria surfaced. Some determinant attributes appeared in interview after interview, while other criteria emerged only once. Therefore, how can one develop a fairly comprehensive list of possible decision attributes when such a large number of criteria surface? One author suggests a popular vote technique, eliminating determinant attributes mentioned by less than 5 percent of the participants (Louviere, 1988:51). Using this procedure successfully reduced the number of criteria by nearly one-half. The reduced set of 1993 determinant attributes, the participants mean rating of their utility, and the number of times it was identified appear in Table 7.

1993 Determinant Attributes

Attribute	Mean	Votes
Literature Review	123.5	2
Alternative Technology	116.0	17
Expert Opinion	114.2	14
Technical Merit	112.8	14
Within Discipline	115.0	4
Cost/Benefit	118.8	4
Efficiency (Performance)	108.8	4
Zero Sum (against other proj)	103.3	3
Cost Factors	114.2	13
Funding Availability	97.3	8
Risk	116.8	12
Environment	94.3	3
Prior Supporting Research	122.7	14
DoD Need	115.3	6
User Need	132.7	22
USAF Mission	131.8	15
Can it be Produced	96.7	4
Sunk Costs	94.0	4
Test Plan	82.7	4
Payoff/Mission Potential	135.0	7
Multi-Service Option	107.3	4
Industrial Base Impact	100.0	3
Organic Facilities	87.0	2
Time (Schedule)	103.3	9
Meet 10 ILS Elements	86.4	7
Life Cycle Costs	100.3	4
Cost Figure Accuracy	98.7	3
Technology Feasibility	124.3	14
Manpower	94.2	2
State of the Art	130.3	4

Table 7. **1993 Determinant Attributes**

Trying to build a decision model on twenty-nine criteria may prove too complicated for experimental testing. However, several techniques exist for reducing the list further. For example, Louviere notes that participants may propose composite or "fuzzy" concepts instead of actionable decision attributes. He identified quality and convenience as concepts fitting this category, suggesting that they may carry different meanings to different people. Louviere advised using conjoint techniques to define them in a function (Louviere, 1988:52).

A second option would be to perform a factor analysis together with a varimax routine, combining the factors and the data base values, and perform an analysis of variance. One could repeat the process until the original listing of criteria distilled into an orthogonal grouping small enough to test experimentally. Unfortunately, the thirty-six participants in the 1993 interviews provide a data base too small for a quality analysis using factor analysis.

A third procedure for grouping the criteria might be correlation analysis. If a strong correlation existed between two criteria, then perhaps one could cancel or completely explain the other, thus permitting elimination of one or more determinant attributes from the table. For example, a strong inverse correlation, -0.93693, with a p-value of .0019 surfaced between the determinant attributes "risk" and "expert opinion." This statistic suggests that the decision makers felt a substantially reduced project risk in the light of favorable expert opinion. Therefore, when reducing a massive criterion listing such as this, one need only consider using either "risk" or "expert opinion," but not both. Unfortunately, not enough correlations presented themselves to substantially reduce the 1993 list of candidate criteria into a small experimentally acceptable set.

Alternatively, one could continue using Louviere's method by raising the cut-off percentage threshold far above the original 5 percent. Applying this routine reduced the 1993 determinant attribute list to seven potential criteria. The top

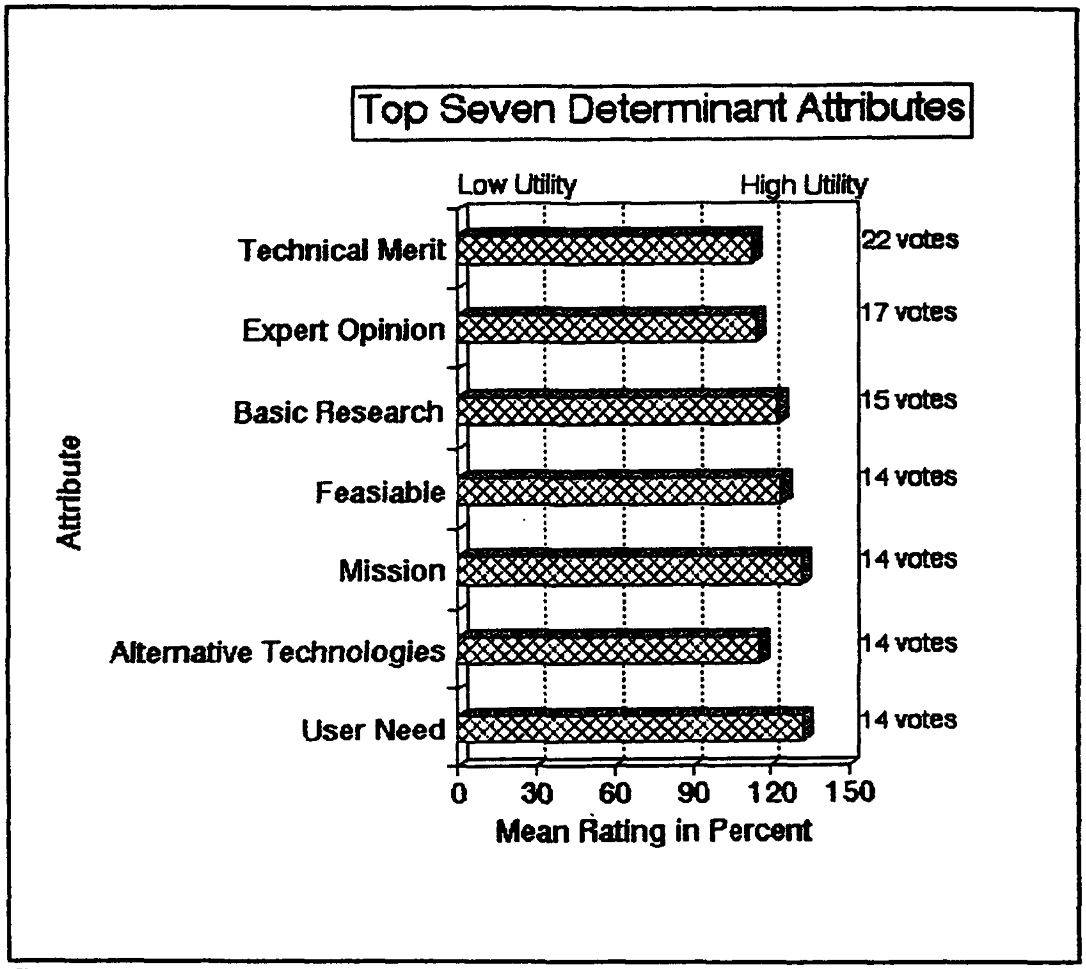


Figure 46. **Top Seven 1993 Determinant Attributes**

seven 1993 determinant criteria, their mean rating of utility on a scale form zero to 150, and the number of people voicing them are shown in the Figure 46.

Mention should be made of the potential for variability in criterion usage and beta weight in a large laboratory environment. Brooks found that managers of 6.2 level projects used different criteria beta weights than managers of 6.3 projects (Brooks, 1979:72). Additionally, he determined that each directorate placed different relative weights upon determinant attributes by using a Chow's F-test (Brooks, 1979:76). Further, Brooks concluded that the individuals he surveyed could not accurately specify the weights they placed upon their attributes (Brooks, 1979:81).

Does this mean that any effort to isolate and measure determinant attributes is futile? No! However, any successful employment of Wright Laboratory's decision criteria, its linear models with beta weights, and/or the formal project selection methods, must consider the myriad effects inherent in the decision environment over time, across organizations, and through hierarchical levels.

4.7 Question 4: Effect of a Cost Estimate

What is the part-worth utility of an engineering development cost estimate in a decision maker's choice on a lateral airfoil design?

Section 4.6 above developed a list of determinant attributes for Wright Laboratory. The same interview instrument that recorded participant ratings of the utility of the criteria also requested an assessment on the utility of an engineering development cost estimate. Remember that the lateral airfoil research project presented to the participants showed a fairly developed form.

Each subject was verbally requested to make their evaluation not on the dollar figure, but on the fact that they had an estimate at that juncture. Amazingly, this criterion received the lowest mean utility appraisal of all criteria rated. The mean rating on a scale from zero to 150 was 78.3. Generally, the participants felt it was more important to have a test plan than a cost estimate. Additionally, the Spearman rank correlation failed to show any significant correlation for the cost estimate with the other determinant attributes advanced at the .05 significance level.

SAS/STAT paired comparison of means procedures for the engineering development cost estimate against the other six 1979 criteria led to rejection of the null hypothesis that the mean scores were statistically equal at $\alpha = .05$ level of significance. The p value for the tests ranged from .07 for the determinant attribute "Time" to 0.00 for "User Need." This test supports the opinion that Wright Laboratory has low utility for an engineering development cost estimate as a determinant attribute.

Now, one needs to balance this finding with other information gathered during the interview process. Thirteen participants raised "cost factors" as a criterion. The cut-off point for criteria elimination from the top seven listing was arbitrarily set at 14 participants. So, had the list been expanded to eight criteria, than cost factors, collectively, would have surfaced in an important role. Mention of these other cost factors in the Wright Laboratory interview sessions suggests that the decision makers require a different cost factor(s) than the engineering development cost estimate at this juncture in the decision process.

4.8 Chapter Summary

This chapter detailed the results obtained from the survey and interviews conducted while exploring the specific issue and answering the research questions. It uses both narrative and graphic tools to analyze and discuss the results obtained from the data. The following chapter summarizes the key findings presented in Chapter IV and lists specific recommendations for the Wright Laboratory project selection process as well as future research recommendations for other research efforts including lateral airfoils.

V. Conclusions and Recommendations

5.1 Introduction

This chapter contributes an abridged précis of the research findings and recommends future research. Generally, the inquiry served USAF, DoD, and national needs for description of techniques used in effective resource allocation. Prior studies on Wright Laboratory complemented with this research methodology and results have appeared in prior chapters. Discussions and recommendations included in this chapter spring from the research questions which highlighted unique facets of the research objectives. The format includes recommendations for future research on each question.

5.2 Question 1: Project Selection Methods

What methods do managers use to select R&D projects and allocate laboratory resources at Wright Laboratories?

5.2.a Findings. The existence of previous research by Prince (1985) and Congdon (1988) provided a historical benchmark for understanding Wright Laboratory's processes and tools while the SAS/STAT software calculations of 1993 survey results accurately measured the environment. Six important and positive conclusions follow from the research.

1. Wright Laboratory uses many of the published and well documented formal project selection techniques. The study results reflect a large organization adapting technique usage through the years, across organizational structure, and down hierarchical levels to meet unique decision environments.

2. Wright Laboratory displays a greater tendency to use formal method today than was demonstrated in Prince's 1985 or Congdon's 1988 study.

3. Wright Laboratory prefers using Checklist, Scoring, and Sorting models although the survey identified a healthy familiarity rate with many other published decision making methods.

4. Wright Laboratory demonstrates that formal technique usage is not predicated upon familiarity. For example, a large percent were familiar with the cost/benefit ratio method, but very few used it.

5. Wright Laboratory expresses uncertainty on if a formal project selection technique could be developed that would be useful during the project selection and resource allocation process, but expressed a willingness to participate in a formal project selection class if offered.

6. Wright Laboratory shows a greater tendency to use a formal decision making technique as the dollar value of the judgment increases. Further, the laboratory showed that formal methods have uses when money is not a factor.

5.2.b Recommendations. Specific recommendations follow from survey and interview results. The interviews provided insight into the directorates personalities. For example, survey statistics clearly show that Materials directorate has a strong preference for using formal decision making methods. Yet, statistical numbers hide the enthusiasm conveyed during personal interviews. Naturally, a first recommendation follows from an appreciation of the directorates knowledge of formal decision making methods and statistical verification of an overall ardor within the organization for a deeper understanding.

1. Wright Laboratory should encourage continued education in decision making methods appropriate for R&D Project Selection. This could include inter-organization communication (crossfeed/crosstell) of formal method experiences for both successes and failures.

A second recommendation targets postgraduate educational institutions and results from Wright Laboratory's statistically large population of Master degree personnel with Engineering majors.

2. Educational institutions should encourage classes on formal decision making methods at the masters level, particularly for engineers.

Recommendation three has a historical and statistical information basis, but originates from my personal observations while trying to fathom the complexities of published decision making methods. The recommendation build on Prince's observation that laboratory personnel preferred "relatively simple and easy to use" techniques (Prince, 1985:38).

3. The propensity of usage rates for simple techniques suggests a lack of understanding for the more rigorous methods. Authors familiar with formal

project selection techniques should communicate those techniques in both engineering and management vernacular.

A final recommendation concerns future research, noting that Wright Laboratory's decision making environment is, perhaps, no less complex than many other agencies within and without government. The potential and consequences of mismanagement warrant continued high level interest and journalistic attention like that displayed in institutional research (Brooks, 1979; Prince, 1985; and Congdon, 1988) and industry trade magazines (Lavitt, 1993:17).

4. Studies of R&D project selection technique usage needs to be published on other Air Force and DoD laboratories to complement this study and meet OTA's challenge of encouraging research performers to address these national needs (OTA, 1991:43). Additional studies could focus on 6.1 level decision processes at government agencies like the Office of Scientific Research, and the Advanced Research Projects Agency.

5.3 Question 2: Lateral Airfoil Research Viability

What establishes lateral airfoils as a potentially viable research project?

5.3.a Findings. The abundance of bibliometric evidence from patents detailed in Appendix A establish lateral airfoil technologies' research merit. This observation needs to be balanced by interview respondents' reaction to a potential $210 million dollar engineering development project. A majority of participants suggested that they required a much deeper understanding of the technology's fundamental scientific underpinning prior to any wholesale commitment. Interestingly, Wright Laboratory interview statistics show that bibliometric evidence is a positive indicator for research potential.

5.3.b Recommendations. Basic research needs to be done to establish a better understanding of lateral airfoil potential.

5.4 Question 3: Attributes Used in Portfolio Selection

What determinate attributes do decision makers use in the final choice set during research program portfolio selection?

5.4.a Findings. Exploratory research suggests Wright Laboratory has numerous important criteria for applied research decision processes. The initial list of 60 discrete items was reduced to the seven popular attributes shown below.

1. Does the project have **Technical Merit**
2. Has it received positive **Expert Opinion**
3. Does supporting **Basic Research** data exist
4. Does it appear **Feasible**
5. Does it meet an Air Force **Mission**
6. Do **Alternative Technologies** already exist
7. Has there been an expressed **User Need**

Some of these determinant attributes compare favorably with Stahl and Harrell (Brooks, 1979) original six while others surface for the first time in this study.

5.4.b Recommendations. The 1993 interview results qualified as an exploratory study on this subject. Further research needs to be done to establish the relative merits of these attributes, leading to a predictive model. A larger, follow-on statistical sampling could exploit these popular decision attributes. A more in-depth study could explore determinant attribute interactions for the large list of 30 criteria that were identified by laboratory personnel. Factor analysis procedures based on experimental results could accurately determine discrete criteria's interactions.

5.5 Question 4: Effect of Cost Estimate

What is the part-worth utility of an engineering development cost estimate in the decision maker's choice on a lateral airfoil design?

5.5.a Findings. This exploratory study found that the engineering development cost estimate has little part-worth utility to Wright Laboratory decision makers on applied research projects. Overall, the decision makers rated this criterion with the lowest mean utility of any criteria either mentioned by the interview participant or presented for consideration by the interviewer. However, Wright Laboratory decision makers do include other cost factors as determinant attributes in their decisions process.

5.5.b Recommendations. Additional research needs to be done to establish what level of decision maker uses an engineering development cost estimate. Additionally, this research could focus on identifying all cost criteria for discrete organizational sub-populations as well as the appropriate user levels for the engineering development cost estimate as a determinant attribute.

5.6 Chapter Summary

This chapter completes the study on Wright Laboratory's current decision making criteria and methods. A battery of findings and recommendations were addressed for each of the research questions. The study examined familiarity and usage rates for fifteen published R&D project selection methods and found that the laboratory displayed a greater tendency to use formal methods in 1993 than was shown in prior research. Further, the study showed the organization exercised different techniques through the years to meet unique decision environments. An overall preference for simpler models like Checklist, Scoring, and Sorting models led to a recommendation that authors familiar with the other techniques communicate them in engineering and management vernacular.

Secondly, the study introduced a technological paradigm, lateral airfoils. A bibliometric search for patent designs dating to 1910 suggested a sustained trend in the technology's art and application. A recommendation was advanced calling for basic research initiatives on lateral airfoils leading to a better understanding of the technology's potential.

Lastly, the study used a "placebo" lateral airfoil research project to gauge Wright Laboratory's decision making process and identified thirty discrete decision making criteria. Seven determinant attributes were distilled from this large body of criteria. The last research initiative led to a recommendation for subsequent modeling of Wright Laboratory's decision process using the 1993 findings.

Appendix A: Lateral Airfoil Bibliometrics

A.1 Lateral Airfoil Technology

This appendix provides an appraisal of three applications for lateral airfoil technology. Lateral airfoils typify a technology that the Air Force would research. They have an unknown usefullness and efficiency potential. However, these bibliometrics from United States patents suggests they may have specific applications on aerospace vehicles. The patents serves as the springboard for discussion of lateral airfoil concept and potential.

Lateral airfoils perform the same function on an aerospace vehicle as the main rotor blades do on a modern helicopter. The helicopter's main rotor blades 'rotate' in a plane above the fuselage or helicopter body providing lift and thrust. Lateral airfoils render the same performance while 'revolving' in a cylinder around or outboard of the aerospace vehicle's fuselage. Copies of certain applicable United States patents are used in this appendix to both explain the concept and provide a historical overview of their technological maturation process.

Precedents for legal patents began centuries ago. Today, U.S. patents receive their legal authority from Article 1, Section 8 of the United States Constitution and the 1790 patent laws. U.S. patents are issued only after the Patent Office is convienced that the new idea works, but it is important to note that a patent does not establish airworthiness. The lateral airfoil designs shown in the next paragraphs represent what many inventors considered as a truly remarkable discovery or innovation for their time. Their patents captured both the designers dreams and best understanding of the concepts. This survey acknowledges their contribution to lateral airfoil understanding while establishing a trend in thought focused on a promising design that offers unique operational characteristics and enhanced capabilities for aerospace flight.

There are many novel designs documented with the Federal Government. Every attempt has been given to exhaustively survey all pertinent United States Patents, but some one or more patents may have been overlooked that describe or significantly enhance knowledge on lateral airfoils. The patents and descriptions presented here were gathered through a patent search commissioned by the author in 1978 and through a "LEXIS" data base search using the key phrases: (rotat! or mov!)+(wing or airfoil)+(lateral w/5 airfoil). Again, inclusion of a particular patent in the following text does not serve as a airworthness validation for any particular design.

A.1.a Kincannon. The first patent of interest was an invention by Leo Covington Kincannon from Santa Cruz county California, USA (Kincannon, 1910). Kincannon used the lateral airfoil idea, referencing it as

> ***two or more pairs of wings, each pair being composed of six separate wings. The wings are mounted to revolve about an axis and also caused to be intermittently rotated, so that for a portion of their travel, they will be in a plane parallel with the general plane or direction of motion of the flying machine. (Kincannon, 1910:1)***

His legal language is better understood when coupled with the inventor's drawings of the design. The next figure shows the inventor's sectional view which he titled Fig. 3, but appears in this text as Figure 47. This single drawing of the flying machine is sufficient to explain the lateral airfoil application. Kincannon's design as shown had two sets of lateral airfoils rotating outboard of the fuselage. Two

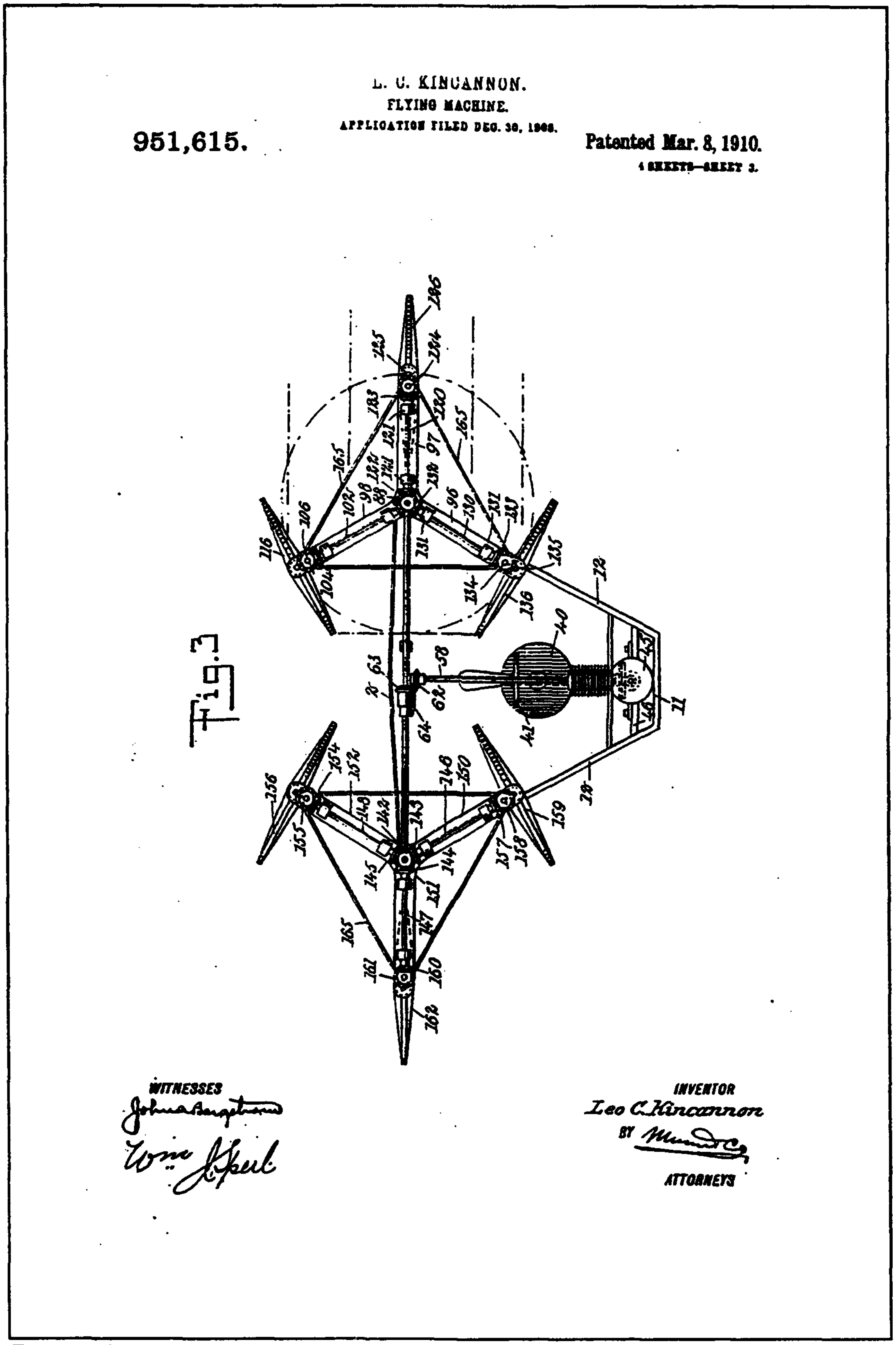


Figure 47. **Kincannon Patent of 1910 (Kincannon, 1910)**

other sets of lateral airfoils are removed for the sectional drawing. These sets of wings were powered by a series of drive shafts and gears connected to an engine so that the wings revolved. The inventor did note that the gears worked to "drive the shafts . . . in opposite directions" which suggests that a potential torque factor was considered (Kincannon, 1910:2).

Kincannon incorporated a series of complicated changes in angle of attack for the wings in their cylinders of revolution. He described the wings parallel with the plane of revolution near the fuselage and perpendicular to the plane of revolution outboard of the fuselage. This detail is plainly shown in his drawing with wings labeled 162 and 126. Evidently, the inventor intended that the wings push enough air down, while outboard of the fuselage, to overcone weight and sustain flight. It is unclear if the design would sustain flight for any length of time, but the lateral airfoils certainly would have churned the air.

While Kincannon's design lacked many of the conventional controls found on modern aircraft, he did include a propeller for thrust and a rudder for yaw control. He successfully patented the first concept for airfoils revolving outboard of the fuselage to produce lift.

A.1.b Jones. Lloyd Jones of Las Animas, Colorado received a lateral airfoil patent on December 17, 1918. The inventor's drawing from the patent application appears in Figure 48. He called his invention an "improved type of aeroplane embodying helicopter principles of construction" (Jones, 1918:1). His design used lateral airfoils that may have produced both lift and thrust. While it is clear that Jones understood the concept of auto-rotation and recognized that the lateral airfoils could stablize the aircraft during auto-rotation much like the

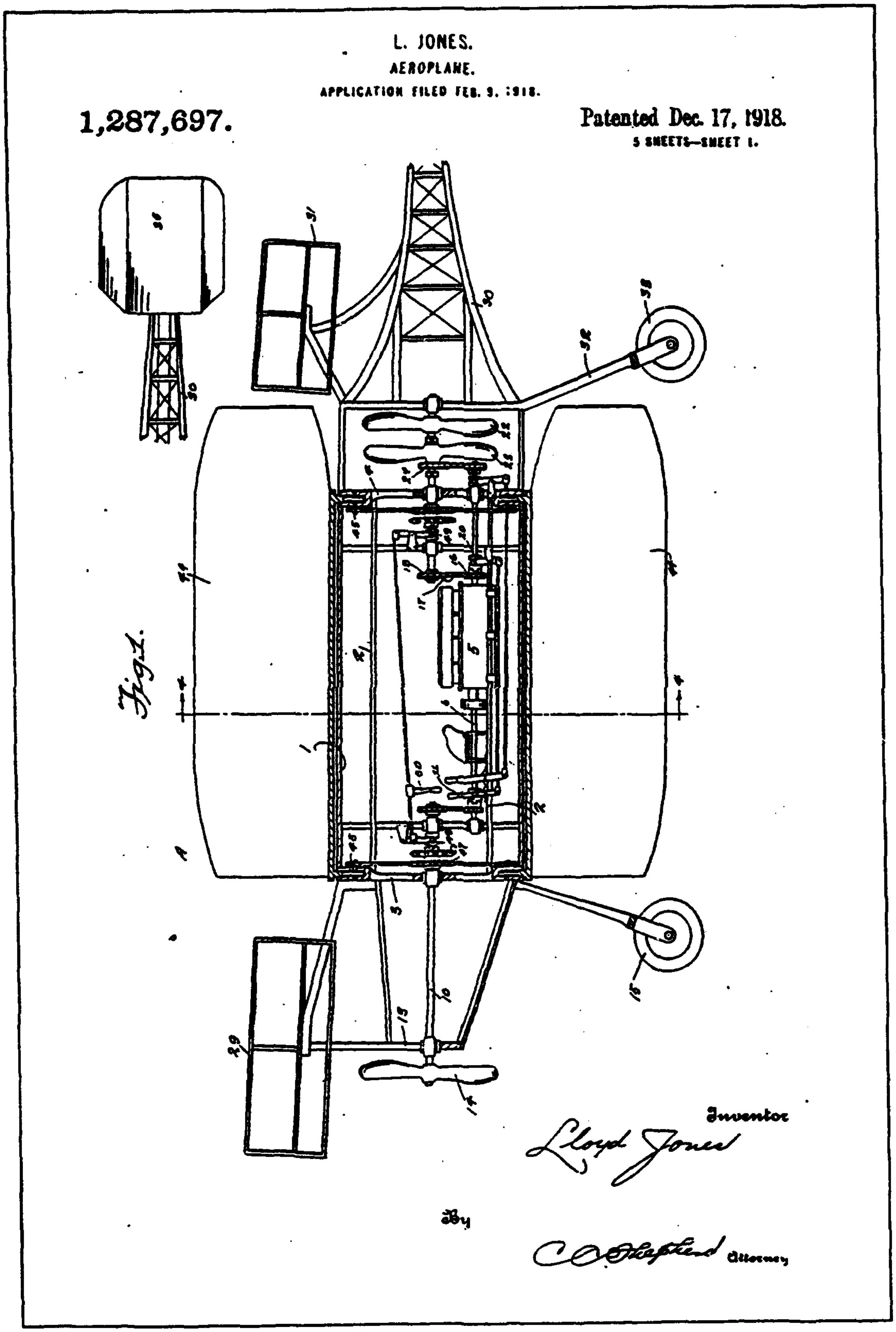


Figure 48. **Jones Patent of 1918 (Jones 1918)**

helicopter's main rotor baldes, it is unclear if the inventor intended for the engines to drive the lateral airfoils during flight (Jones, 1918:1). The drawing shows a section view taken through the vehicle.

Jones used conventional control surfaces like the rudder and aileron to "assist in controlling the lateral and vertical movements of the aeroplane" and forward and rearward elevators which could be "synchronously oscillated" (Jones, 1918:2). For thrust, he used three propellers in his design, two for propulsion and one for braking.

Jones' lateral airfoils were helical and revolved around the fuselage. His design allowed the wings to whirl around the fuselage as the vehicle moved through the air. The engines could be coupled to the lateral airfoil, but the coupling described in detail was for auto-rotation where the airfoils drove the propellers and/or engine. Interristingly, Jones contended for the possibility of vertical flight, if the pilot could skillfully operate the controls. His patent successfully described the lateral airfoils' auto-rotational capability and introduced its' potential for vertical flight application.

A.1.c Burrill. Elvyn Fremont Burrill of Berkeley, California filed his patent application on 10 August 1923. Nearly two years later the United States Patent Office granted his patent for a "new and useful flying machine" (Burrill, 1925:1). He described a machine with counter routating lateral airfoils on twin spools outboard of the fuselage (see Figure 49). The design produced thrust which could overcome the vehicles weight and propell it vertically upward. Additionally, he described a helical curve on the blades that could produce axial thrust for propulsion. Burrill vectored the thrust from the lateral airfoils and manipulated

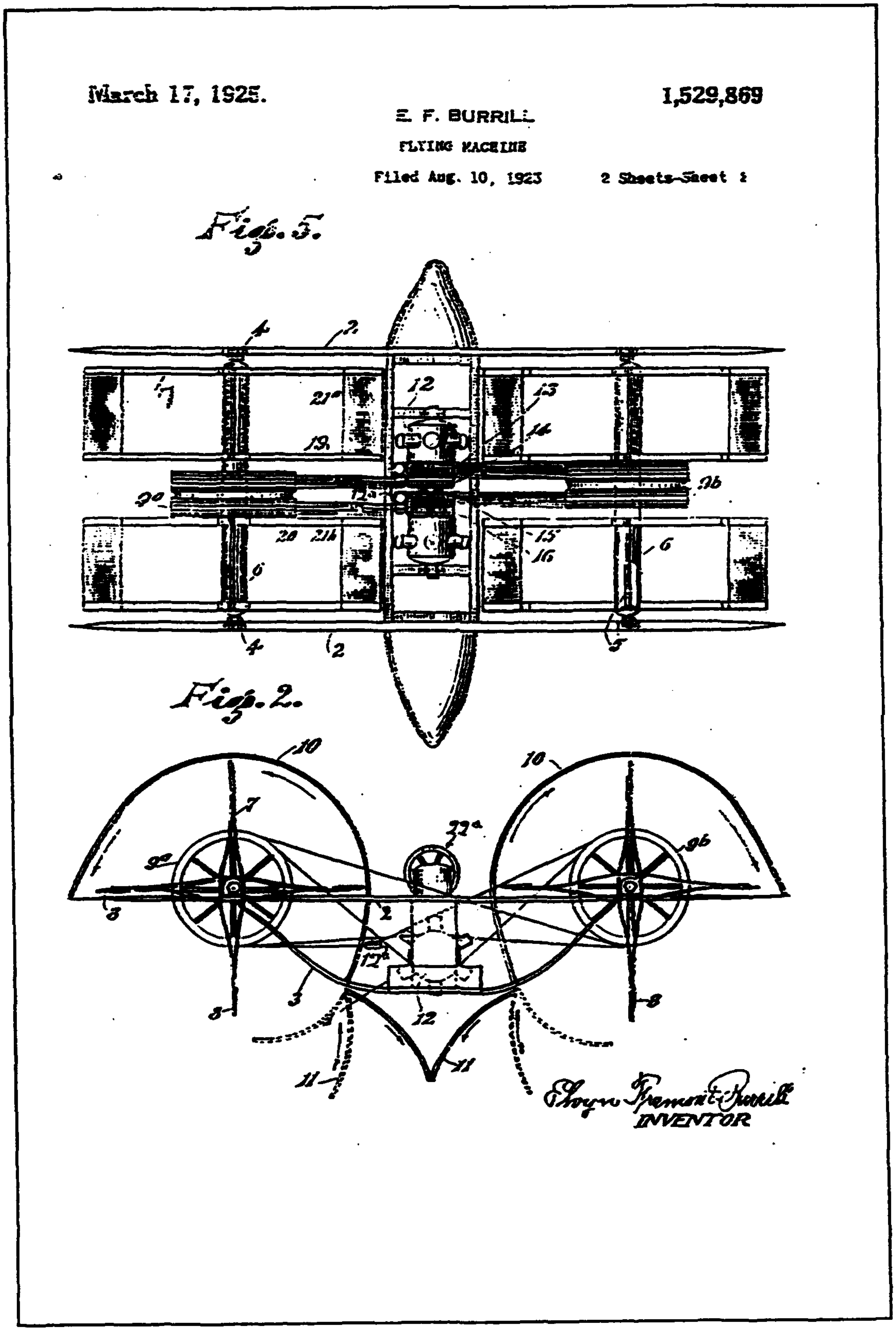


Figure 49. **Burrill Patent of 1923 (Burrill, 1923)**

the engine speed to control the lift vector. He used two engines to independently drive the schrouded lateral airfoils.

Burrill's design lacked any pitch change method for the lateral airfoil's wings or blades. He envoked directional control by manipulating the center of gravity using a sliding pilot's seat. A design which truly let the pilot fly by the seat of his pants.

Burrill used lateral airfoils to achieve vertical flight, hover, and transition to horizontal flight. He described the effects of variable wing or blade speed and thrust vectoring.

A.1.d. Watter. In 1927 Michael Watter received a patent for his heavier than air lateral airfoil design. His document was a refile for an abandoned application first filed on 25 April 1922. This places the original design before Burrill's application, but since the patent was granted in 1927, a date subsequent to Burrill's, its' discussion apropriately falls here in the chronological sequence.

Watter's concept used "one or more planes or wings . . . mounted to move in a rectilinear direction" (Watter, 1927:1). Sheet one drawings of the inventor's design appear on the following page (see Figure 50) and show a lateral airfoil which revolves in an oblong manner. The wings travel across the upper surface of the fuselage, along the fuselage sides, and complete their journey inside the "flying machine" (Watters, 1927:3). His design, if actually seen in flight, could have appeared as a flattened cigar with both upper and lower vertical stabelizers and left and right horizontal stabilizers. He described a propeller and motor combination at the nose and tail of the vehicle.

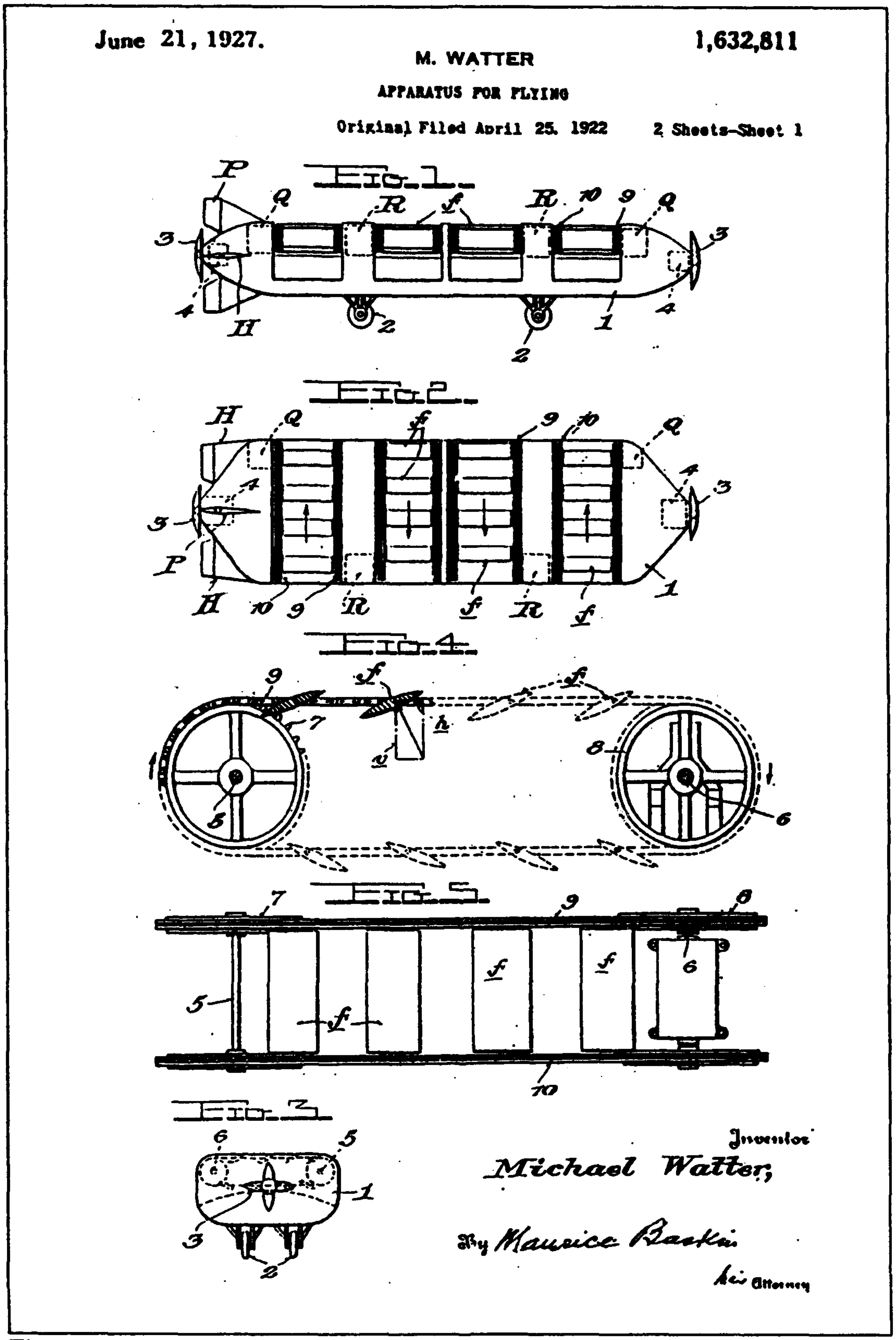


Figure 50. **Watter Patent of 1927 (Watter, 1927)**

Watters design used countra rotating lateral airfoils which eliminated severe torque problems. He wrote that "as one set moves in one direction the other set of planes moves in the opposite direction" (Watters, 1927:1). The set of planes or wings produced lift as air flowed over their surfaces. Watters rigidly attached guide rails to the fuselage which transmitted pitch chang information to the lateral airfoils. So there was no way to vary the pitch short of remounting the guide rails. He wrote that the lateral airfoils could be used by the vehicle for "rising or descending vertically, or hovering in the air over any desired spot" (Watters, 1927:2). Additionally, he suggested that the lateral airfoils placement on the fuselage could be changed. He noted that they could be arranged longitudinally on the fuselage.

Watters contributions included extension of lateral airfoil designs into shapes other than circular. He introduced countra-rotating lateral airfoil sections which eliminated a substantial torque problem.

A.1.e Silver. In the dawn of aviation their was a keen interest among inventors about dirigible airships. At one time they held great promise for airborn battle stations. However, interest faded in dirigibles as a result of numerous problems including the dangers encountered when using highly explosive hydrogen gas to distend the balloon's fabric. Dirigibles have remained a topic for study throughout the years since the highly publicized "Hindenberg" disaster and many fly today.

One of the problems typically encountered with dirigible designs was how to propell the lighter than air vehicle (see Figure 51). Without some type of self propulsion device, the dirigible would simply drift with the wind and be useless for many types of work. Jesse W. Silver, of Tacoma, Washington successfully patented

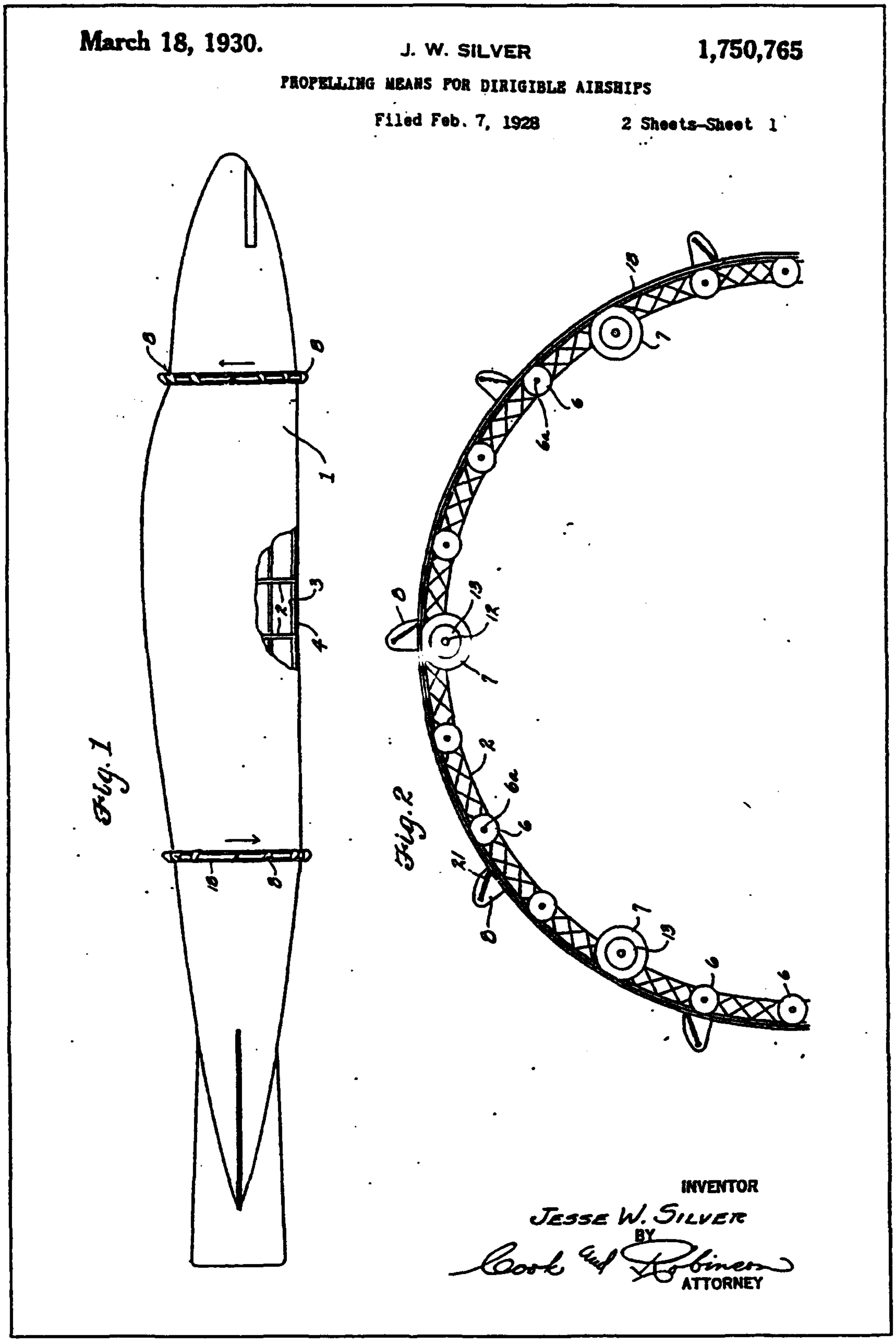


Figure 51. **Silver Patent of 1930 (Silver, 1930)**

a dirigible propulsion design using lateral airfoils which he claimed would "... prepare a unit whereby head resistance to travel of an airship is reduced to a minimum so as to make possible a greater speed" (Silver, 1930:1).

He proposed using two or more lateral airfoils driven by an engine through belts and cables and mounted circumferentially on the ship at specified intervals. He wrote that the vanes or wings would be rigidly fixed at an angle 45 degrees to the belts direction of movement (Silver, 1930:2). He described torque effects which would cause the airship to axially rotate and proposed that the lateral airfoils rotate in opposite directions to negate the undesirable effect. He did not discuss using the lateral airfoils for directional control and considered roll control capabilities only to the extent of overcoming undesirable torque. Silver's design successfully described lateral airfoil application for dirigible airship propulsion.

A.1.f Purpura. August C. Purpura of Berwyn, IL patented a lateral airfoil design in 1956 which was proposed as more efficient in vertical flight than contemporary conventional helicopter design of the 1950's and capable of 200 mph forward velocities (Purpura, 1956:1). He detailed a single lateral airfoil which revolved around the fuselage aft of the cockpit (see Figure 52). The lateral airfoil blades were connected to a steel spring wire encased in rubber and powered by either of two engines. As the pilot moved a control shaft to the right or left, he initiated a complicated set of movements through cams and guides to the airfoils revolving around the craft. The pilot's inputs moved a guide up and down, changing the pitch of the lateral airfoil blades or wings, permitting the aviator to "stabilize the aircraft in flight exactly as he could with ailerons in conventional airplanes" (Purpura, 1956:2).

March 27, 1956 A. C. PURPURA 2,739,768

AIRCRAFT HAVING FEATHERING AIRFOILS

Filed Sept. 27, 1954 4 Sheets-Sheet 1

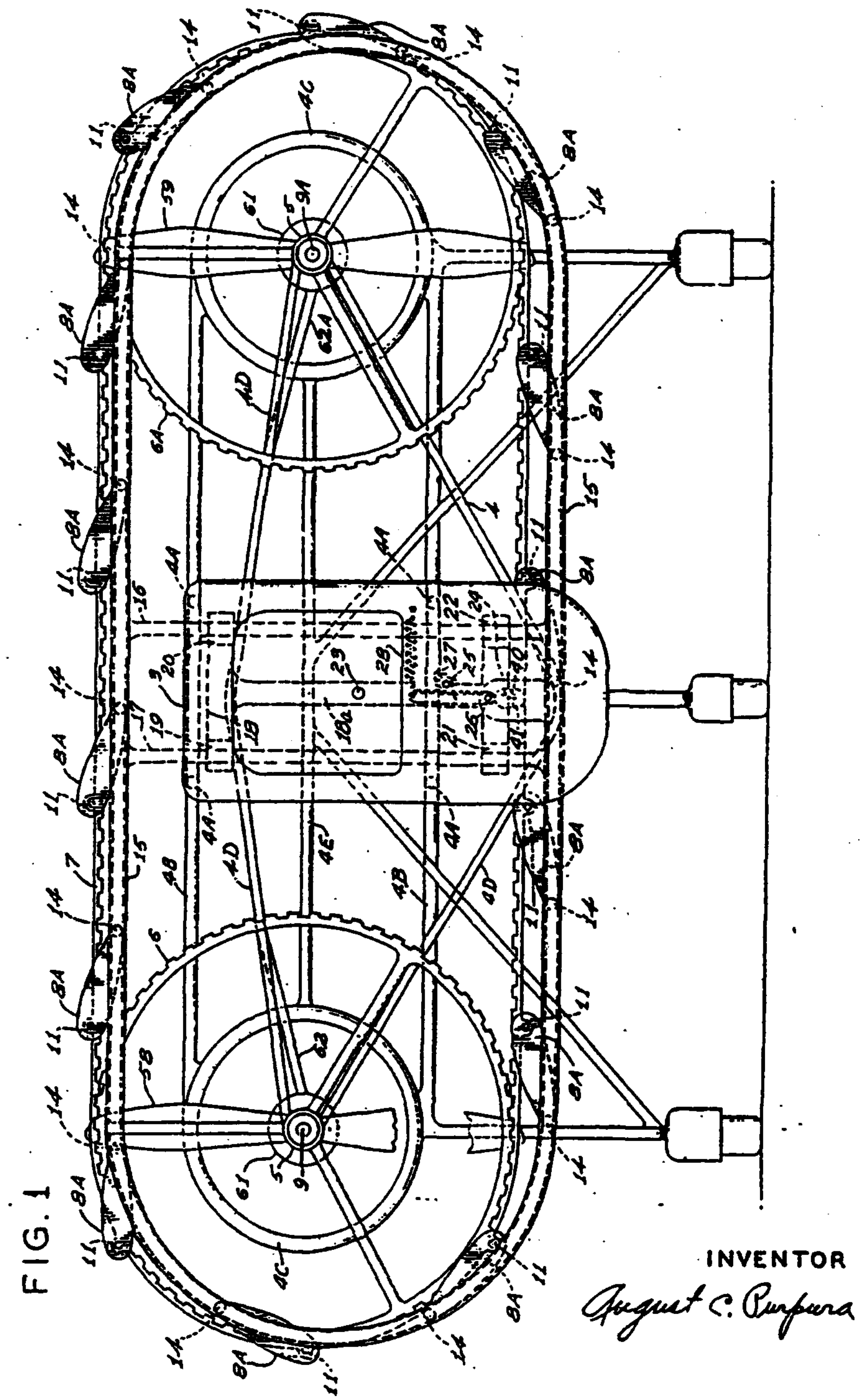


Figure 52. **Purpura Patent of 1956 (Purpura, 1956)**

The craft utilized a conventional rudder and elevator for yaw and pitch control. Two controllable pitch propellers supplied thrust. Interrestingly, Purpura countered the torque from the lateral airfoil with the propellers that were rotated in the opposite direction.

The design recognized an engine out situation. "Overrunning clutches" would decouple the engine from the propellers which would allow the propellers, now driven by the wind, to power the lateral airfoil. Purpura did not mention any autorotational effect on the lateral airfoil itself.

Purpura's patent developed controllable pitch for lateral airfoil blades or wings. He described a lateral airfoil system that provided lift, but no thrust. Further, his design described lateral airfoil track other than circular.

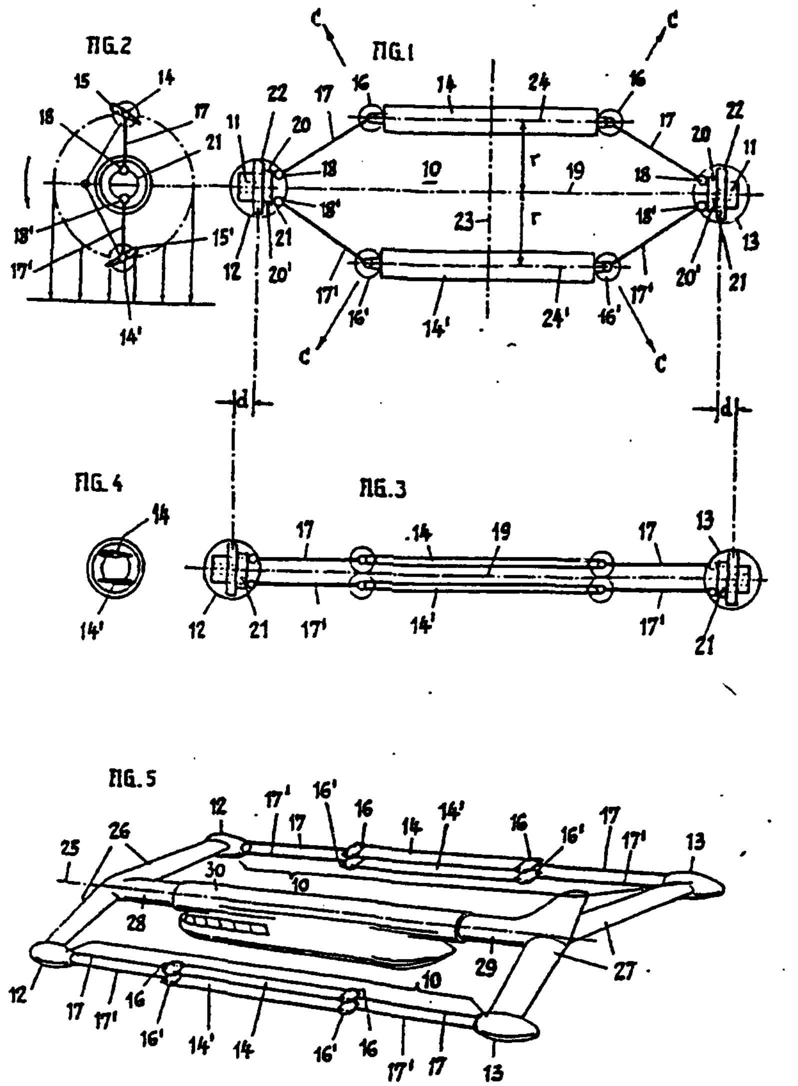
A.1.g Fischer. Not all Patents granted for lateral airfoils originated in the USA (see Figure 53). One such United States patent was granted to Hans W. Fischer for a *Driven Rotor-Wing System for Aircraft* of Steffisburg, Switzerland on Janurary 25, 1966. His design used lateral airfoils that revolved outboard of the fuselage "according to the known Voith-Schnider principle" (Fischer, 1966:1). Voith Schnider propellers receive a deeper discussion in Section 2.5.c. Generally, they are used on marine vehicles requiring great maneuverability qualities, like under-water mine hunters and passenger ferries.

Fischer described lateral airfoil blades with variable angle of incidence from "zero to positive values and back again to negative values in the cource of each full revolution" (Fischer, 1966:1). This action resulted in in a constant engine r.p.m., while varing the thrust vector's direction and magnitude. Further, the blades were mounted "so that the distance between their longitudinal axes and the rotor axis"

Jan. 25, 1966 H. W. FISCHER 3,231,220

DRIVEN ROTOR-WING SYSTEM FOR AIRCRAFT

Filed March 10, 1964



Inventor
Hans W. Fischer
by Michael J. Striker
Attorney

Figure 53. **Fischer Patent of 1966 (Fisher, 1966)**

facilitating a variable lift vector (Fischer, 1966:2).

Fischer's design was considerably more astethically pleasing than any previous lateral airfoil design. He described an aerospace vehicle capable of vertical take off or landing. His discussed the need for variable angle of incidence for the blades, but neglicated their contribution to pitch, roll, and yaw control. He described a twin lateral airfoil system, but did not discuss potential problems with differential lift or thrust vectors from the systems.

Fischer's patent was the first to envoke a documented scientific principle, (Voith-Schnider) to support the design. Further, he opened the door for lateral airfoil applications in the marine environment.

A.1.h Dell'Aquilla. American Patent laws allow inventors to asign their patents to business entities. Joseph L. Dell'Aquilla listed the Wendros Company, Hicksville, N.Y. as the assignee making his the first patent on lateral airfoils to do so (see Figure 54). His 1974 patent included 13 claims and 12 drawing figures which described a lateral airfoil aerospace vehicle "capable of omnidirectional flight having a plurality of" blades or wings revolving outboard of the fuselage (Dell'Aquila, 1974:1).

Dell'Aquila's listed five specific objectives, which describe potential advantages of the lateral airfoil design over the conventional helicopter. They are listed on page 127.

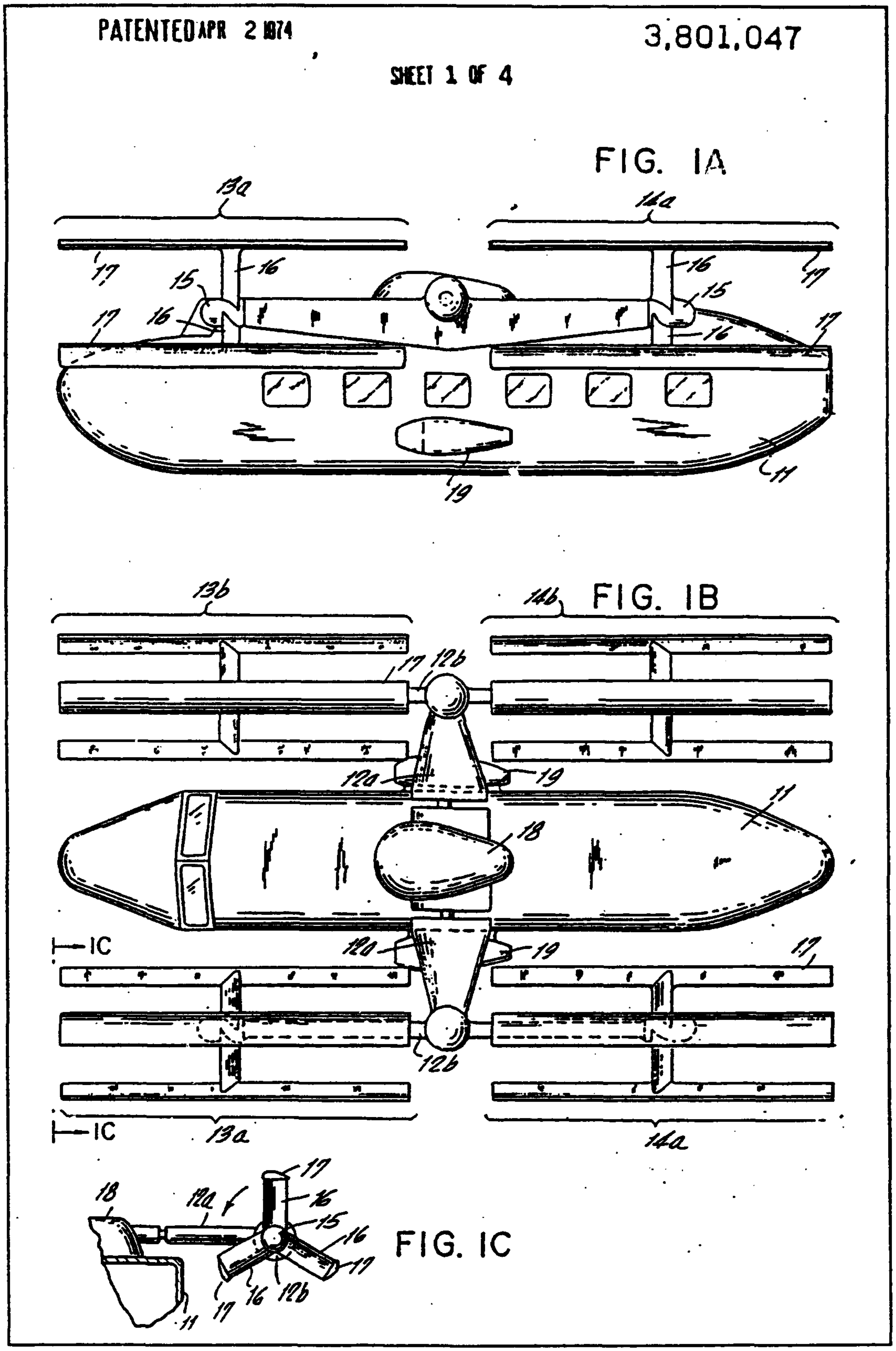


Figure 54. **Dell'Aquilla Patent of 1974 (Dell'Aquilla, 1974)**

1. *A rotary wing aircraft not subject to gyroscopic, transitional and pendulum effects found with conventional helicopters.*

2. *An aerospace vehicle capable of vertical takeoff or landing free of retreating blade stall characteristics, and thus capable of greater velocities than a conventional helicopter.*

3. *A rotary wing aerospace vehicle with blades free of to stress reversals.*

4. *An aerospace vehicle with vastly improved size and altitude limitations compared to the conventional helicopter.*

5. *An aerospace vehicle with decresed sensitivity to center of lift and center of gravity stability problems commonly exercabated by high airspeed in conventional helicopter designs. (Dell'Aquila, 1974:2)*

Dell'Aquila's drawings, supplied with the patent and copied here, show a craft with four lateral airfoil sections revolving outboard of the fuselage. His patent described in detail how the blade angles could be varied to control lift and how changes in blade angle could contribute to yaw, pitch, and roll control. He described lift vectors for the lateral airfoil sections both singlely and in combination, as well as for ascending, descending, and lateral motion. He realized that propellers and/or propulsion means could be incorporated into the lateral airfoil support structure and that the propeller could directly drive blades as the aerospace vehicle traveled forward through windmilling (Dell'Aquila, 1974:5). Further, he described both forward and reverse thrust from the lateral airfoils.

Dell'Aquila's patent advanced new lateral airfoil concepts and understanding while repeating many of the capabilities discussed by earlier inventors. His patent discussed mechanical, hydraulic and electrical means for varying lateral airfoil blade angle using a cam and cam follower (Dell'Aquila, 1974:6). Additionally, he noted that lift was created by the lateral airfoil blades at "both the top and bottom of the rotational cycle" and described a compensation the downwash effect (Dell'Aquila, 1974:2).

A.2 Appendix Summary

This appendix presented an a view of lateral airfoil patents granted for aerospace vehicle designs since 1910. The bibliometric evidence suggests a sustained trend in thought and application for the concept. The patent search on lateral airfoil's is not exhaustive. Additionally, other disciplines may incorporate this technology. Examples may include turbine engine designs and naval propulsion applications.

Appendix B: R&D Project Selection Techniques

B.1 Introduction

The appendix partitions a very broad topic. The study encompasses R&D review methodologies, or decision making tools, used by agencies with research allocation authority. Typically, these review processes may include peer review, solicitation of outside expert advice, or program manager judgment. Specific methodologies used by individuals or groups may include quantitative factors like an Internal Rate of Return (IRR) or qualitative factors like research importance, spin-off implications and portfolio variety or homogeneity. The discussion includes a *limited* examination of R&D project selection models currently in vogue, including their strength, weaknesses, and literary references. The presentation format targets managers who desire a grasp for the methodologies without a first getting a fundamental understanding of their technicalities. The collection here does not exist elsewhere in literature. Economic, scoring, constrained optimization, and decision theory models typify the material discussed. Please remember that data on this subject is extensive. The following information serves to introduce the subject and acquaint the reader with terms used. Baker and Pond (1964); Cetron, Martino, and Roepke (1967); Souder (1978); and Jackson (1983) each give far more exhaustive reviews of R&D project evaluation methods while Gear, Lockett and Pearson (1971) tailored their review to the subset of techniques known as R&D project portfolio methodologies.

B.2 Checklist & Scoring Models

Many authors consider these as basic, conceptually simple techniques. They are the outgrowths of post World War II industrial expansion. Interestingly, some authors submit that these techniques receive broader use nearly a half a century later while other, more mathematically rigorous methods find only narrow application (Liberatore and Titus, 1983; Watts and Higgins, 1987).

Checklist Model: Many performance criteria are listed. Each project is evaluated as either meeting or not meeting the criteria. A check mark is made when a criterion is met. No check mark shows a criterion was not met. After successfully evaluating all the criteria, each project receives a value equal to the sum of its check marks. Alternate forms of this technique may incorporate several individuals' ratings.

Strength: Simple to use
Easy match of criteria to available information
Easily accommodates qualitative data

Weakness: Overlooks problem complexities
No way to ensure rater used proper consideration
Overlooks problem interrelations
No prioritization of individual factors
Adversely affected by inaccurate information

Readings: (Ansoff, 1962; Moore and Baker, 1969; Gaver and Srinivasan, 1972; Augood, 1973; Souder, 1975; Jackson, 1983; Souder and Mandakovic, 1986)

Scoring Model: *"Checklists or profile charts for different projects are difficult to compare because individual criteria are not weighted. Scoring models attempt to remedy this problem by assigning weights to individual criteria and summarizing the results as a single project score. To arrive at a set of criteria weights, it is necessary to extract preference functions from the decision makers." (Jackson, 1983)*

Strength: Simple, easy to use
Flexible
Easily developed standards
Considers a range of both economic and noneconomic data
Provides a single number evaluation for each project

Weakness: Considers only competing projects
Lack of mathematical rigor promotes questionable results
Dimensionless and useless for rank order comparisons
Requires more information than the checklist

Readings: (Jackson, 1983; Moore and Baker, 1969; Gibson, 1981; Krawiec, 1984; Roessner, 1985; Souder and Mandakovic, 1986)

B.3 Economic Models

These models rank a project on its potential to provide monetary benefits over time.

Cost/Benefit model: ***"Money valuation is the soul of benefit-cost analysis: assessing the good and bad aspects of decision alternatives by valuing them in terms of money. Benefit-cost analysis - synonymous with cost-benefit analysis and abbreviated as B/C or C/B - uses monetary valuation to achieve commensurability of all decision attributes. An attribute valued as equalivent to a one dollar gain is usually considered to be canceled by another attribute valued as equalivent to a one dollar loss. With this perspective, the difference between benefits (good attributes) and costs (bad attributes) is considered to be the objective function in benefit-cost analysis." (Thompson, 1980)***

Strength: Forces quantification of project
Provides a single index for project comparison

Weakness: Not all non-economic factors can be translated into dollars
Not a useful tool for evaluating alternative funding levels
The ratio doesn't reflect any project risk elements
Gives an expected value, not a range of values
Doesn't consider resource constraints
Doesn't consider how the costs and benefits are distributed
Requires significant amounts of information
Tends to lead to status quo
Contingent on existing distribution of income and wealth
The opportunity costs are difficult to estimate if alternative uses are not known

Readings: (Squire and van der Tak, 1975; Irwin, 1978; Thompson, 1980; Jackson, 1983; Smith, 1986)

Payback period: *"Measures the time it will take to recoup, in form of cash inflow from operation, the total dollars invested in a project. The payback method highlights liquidity, which is often an important factor in business decisions. Projects with shorter paybacks (more liquid) are preferred to projects with long paybacks, if all other things are equal." (Horngren and Foster, 1991:681)*

Strength: not affected by accrual accounting conventions like depreciation or depletion.

Weakness: Neglects profitability over lifetime of the investment
Biased against long lived projects with low initial yield
Neglects time value of money
Does not average projects in order of preference

Readings: (Korn and Boyd, 1969; Irwin, 1978; Horngren and Foster, 1991)

Net Present Value: *This technique is a discounted cash flow method of "calculating the expected net monetary gain or loss from a project by discounting all expected future cash inflows and outflows to the present point in time, using required rate of return. Projects with higher net present values are preferred to projects with lower net present values, if all other things are equal." (Horngren and Foster, 1991:675)*

Strength: The result is shown in dollars
Can be used where there is not a constant required rate of return for each year

Weakness: Does not give sufficient consideration to the magnitude of dollar investment and the length of the economic life of the project
Doesn't work well with mutually exclusive projects
Ambiguous about what would happen without the project
Virtually impossible to calculate opportunity costs since all alternatives may not be known

Readings: (Korn and Boyd, 1969; Irwin, 1978; Horngren and Foster, 1991)

Internal Rate of Return: *The internal rate of return is the rate of interest at which the present value of cash inflows from a project equal the present values of expected cash outflows of the project. IRR is sometimes called the time-adjusted rate of return. Projects with higher IRRs are preferred to projects with lower IRR's, if all other things are equal." (Horngren and Foster, 1991:677)*

Strength: Highly accurate
Result is a percentage value
Useful when comparing projects of different size

Weakness: Defective as a measure of mutually exclusive projects
Needs a constant rate of return for each year
Cannot add individual IRR's to obtain an estimate of their combination IRR's.
Returns a single point criteria

Readings: (Korn and Boyd, 1969; Squire and van der Tak, 1975; Irwin, 1978; Horngren and Foster, 1991)

B.4 Constrained Optimization Models

Typically, these models highlight on one or more constraints like money, facilities, or work force. They identify the best candidate through mathematical optimization techniques.

Linear Programming: This technique was pioneered by the Air Force. It returns a solution that attempts to maximize (or minimize) a linear function of the decision variables where the values of the decision variables must satisfy a set of constraints. Each constraint must be expressed as an equation or linear inequality.

"That is the entire problem can be expressed in terms of straight lines, planes, or analogous geometrical figures. There can be no curved surface in any graphical representation of the problem. The mathematical model expressing the problem relates all requirements and management's goals by means of algebraic expressions representing straight lines." (Lapin, 1976:208)

Strength: It can handle large problems with many projects and resource constraints
Supports easy assessment of assumed parameter variation
Supports thorough sensitivity analysis
Optimize benefits while recognizing resource limits

Weakness: Requires a large amount of information
Not adept in uncertain environments
Not adept with interdependence
Benefits must be quantified consistently with objective function specification
Resource requirements must be clearly defined
Limits on resource availability must be identified
Doesn't work with nonlinear relationships

Readings: (Gear, Lockett and Pearson, 1971; Gass, 1975; Lapin, 1976; Asher, 1978; Anker and Tyebjee, 1978; Markland, 1983; Jackson, 1983)

Integer Programming: ***"Simply stated, an integer programming problem is an LP in which some or all of the variables are required to be nonnegative integers." (Winston, 1991:457)***

Strength: Supports fixed charges, either/or constraints, and related ideas
Shares many of the same strengths as Linear Programming
Easily incorporates economic model information

Weakness: Although the feasible region is smaller than a Linear Program, the typical integer Program is usually more difficult to solve.
Not supported with efficient numerical techniques
Hard and time consuming
Large scale problems are practicably unsolvable

Readings: (Hadley, 1964; Gass, 1975; Schrijver, 1986; Winston, 1987, 1991)

Nonlinear Programming: A technique that seeks to maximize or minimize an objective function. The objective function or some of the constraints may or may not be linear.

Strength: Shares many strengths of Linear Programming
Works well with nonlinear relationships

Weakness: Difficult to prove that the local minimums or maximums are global
More mathematically difficult than Linear Programming
Sometimes the procedure returns only approximate optimal solutions

Readings: (Hadley, 1964; Gass, 1965; Winston, 1991)

Dynamic Programming: ***". . .a technique that can be used to solve many optimization problems. In most applications, Dynamic Programming obtains solutions by working backward from the end of a problem toward the beginning, thus breaking up a large Unwieldy problem into a series of smaller, more tractable problems." (Winston, 1991:715)***

Strength: Efficiently handles probability of technical success
The one computational technique that always gives a global optimal solution regardless of the number of local optimums
Works well with multiple period problems

Weakness: Complexities involved in accurately determining probability of success as a function of past and current R&D spending.
Only one resource constraint can be considered at a time

Can become mathematically intractable with progressively larger parameters
Almost all problems need individual specification
Unlike Linear Programming, there is no algorithm which can be applied to universally to all problems

Readings: (Bellman, 1957; Hess, 1962; Hadley, 1964; Trueman, 1974; Jackson, 1983; Bierman, Bonini, and Hausman, 1986; Winston, 1991; Smith, 1991)

0-1 Integer Programming: A special case of integer linear programming where some or all of the variables are forced to take on a unity value (1) or null value (0). Any Integer Program can be reformatted as an equalivent 0-1 Integer Program. Texts on 0-1 Integer Programming typically include a discussion of its abilities to solve capital budgeting problems.

Strength: Reduces a large number of potential projects to a Manageable level
Works well with capital budgeting and fixed charge problems
Works well with either/or constraints

Weakness: Sometimes it proves unsolvable

Readings: (Bush and Richardson, 1974; Fox and others, 1984; Czackowski and Jones, 1986; Winston, 1987)

B.5 Delphi Technique

This techniques uses anonymous judgements on a decision issue solicited from more than one independent source. Initially, the opinions may be gathered through a questionnaire or other format. The participant responses are summarized and the results are sent back to the participants so they can contribute feedback on their peer group evaluations. This cycle may continue in an iterative fashion until the group reaches a satisfactory conclusion.

Strength: No bias effects occurring from face-to-face interaction.
The participants don't have to communicate with each other or be in the same physical location.
Easy for the experts to change their mind
Allows an individual to take a position without all the facts
Easy to contradict superiors without condemnation

Good technique for non-analytical problems
Useful when more individuals needed than can effectively interact face to face.
Good method to use when time and cost factors prohibit group meetings.

Weakness: Slow process driven by participant response cycle
No way for participants to detect distortion of feedback
Repeated use on the same topic with the same participants leads to regurgitation of the same ideas.
Exhibits over-optimism in the short term and over-pessimism in the long range.
The group consensus can overcome the maverick with the better idea.
Participants may use simplistic misjudgments on complex issues.

Readings: (Linstone and Turoff, 1975; Basu, 1977; Dalkey, 1951; Eschenbach and Geistauts, 1985; Parente, Anderson, Myer, and O'Brien, 1984; Nancarrow, 1987)

B.6 Decision Theory Models

These techniques predict the overall success of a sequence of interrelated projects or a project requiring a long time period. They include many specific techniques like Decision Tree, Utility Theory, Fault Tree, and Relevance Tree. Although each of these specific techniques is not discussed in detail here, a synopsis of strengths weaknesses and readings for the group are detailed.

Strength: Ability to consider a wide range of uncertainty
Forces consideration of all interrelated sub-project importance
Yields a meaningful arrangement of complex decision elements without tableau format restrictions
Communicates every course of action and all possible outcomes
Displays interaction between present decision alternatives, uncertain events, and future choices
Easily combines economic methods for a clear portrayal of future alternatives and events

Weakness: Requires a large amount of high quality input data
Highly complex model which may not be understood by all
May not deal adequately with resource constraints
Holds potential of becoming highly complex

Readings: (Hespos and Strassman, 1965; Raiffa, 1968; Trueman, 1974; Lapin, 1976; Balthasar, 1978; Jackson, 1983; Souder and Mandakovic, 1986; Khorramshahgol and Gousty, 1986; Souder, 1975; Jackson, 1983)

B.7 Multiple Criterion Decision Making

These methods are used when the number of alternatives and criteria is large and the job of choosing good alternatives is difficult. The process may result in a satisficing answer as opposed to optimizing answer. Some authors subdivide this category into two distinct halves, multiattribute decision analysis and multiple criteria optimization. Given this division, multiattribute decision analysis is most applicable to problems framed in a context of an uncertain environment with limited alternatives. Multiple criteria optimization works well with deterministic problems with larger numbers of feasible alternate solutions.

It is readily evident that this grouping includes many unique techniques. The discussion is limited to Goal Programming, Interactive Approach, Compromise Programming, ELECTRE approach, Parametric approach, De Novo Programming, Graphic techniques, and Analytical Hierarchy Process (AHP).

Goal Programming: *"As originally conceived, it is the attempt to minimize the set of deviations from prespecified multiple goals, which are considered simultaneously but are weighted according to their importance. In some cases, however, the name "goal programming" has been applied to a procedure which is actually a special case of lexicographical screening, as described by Hobbs (1978). That procedure first determines the alternatives that minimize the deviation of the most important objective from its corresponding goal value. From those alternatives are chosen the ones that minimize the deviation of the second most important objective, from its goal, and so on until all objectives and their goals have been considered." (Zeleney, 1982:281-2)*

Strength: Provides an acceptably good solution to multiple objectives
Works well with multiple incommensurable goals

Weakness: Requires objective function to be linear
Results dependent upon how well goals articulated
Specifying a-priori weights may be difficult
Time consuming: requires decision maker role in formulation, solution, and evaluation

Readings: (Kornbluth, 1973; Naussbaum, 1980; Zeleney, 1982; Markland, 1983; Hannan, 1984; Seo and Sakawa, 1988; Tabucanon, 1988)

Interactive Approach: These techniques assume an existence (known or unknown) of an underlying preference function. Tabucanon wording captures the technique as follows:

"Interactive methods usually consist of a DM (Decision Maker) - analyst or DM-computer dialogue. At each iteration, the decision maker is asked about some tradeoff or preference information based on the current solution in order to determine a new solution. The method essentially assumes that the decision maker is unable to indicate "a priori" preference information due to the complexity of the problem, but that he is able to give preference information on a local level with respect to a particular solution." (Tabucanon, 1988:72)

Strength: Managers can learn from the interactive process
The best MCDM for qualitative criteria

Weakness: Very involved process for busy managers

Readings: (Tabucanon, 1988; Malakooti and Deviprasad, 1989; Venugopal and Narendran, 1990; Reeves and Gonzalez, 1989)

Compromising Programming: ***"Compromise is a natural and necessary outcome of making decisions based on multiple, often conflicting criteria, Ideally, the decision maker would like to completely satisfy all criteria, but that may be impossible in a practical sense. It becomes necessary to "compromise" some or all criteria to some degree while attempting to emulate the ideal solution as closely as possible. Compromise programming attempts to evaluate various solutions based on their mathematical difference, or "distance," from the ideal solution. The best solution is one which either minimizes this distance from the ideal solution, or which maximizes the distance from the "anti-ideal" solution." (Corbett, 1986:17)***

Strength: Solution is the best of all available solutions
Designed for multiple incommensurable goals

Weakness: Results dependent upon accuracy of a-priori weights

Requires articulation of all characteristics used for comparing alternatives

Readings: (Tabucanon, 1988; Zeleney, 1982; Gearhart, 1984; Corbett, 1986)

ELECTRE Approaches: ELECTRE I. Basically, this approach selects a preferred alternative which meets most of the criteria while minimizing the discontent from any one criterion. The results appear in a preference graph with a partial ordering of alternative systems.

ELECTRE II. This results in a complete alternative ordering using the concept of strong and weak ranking relationships. It requires an understanding of the concepts of high, average, and low concordance, and high and average discordance.

Strength: The method handles nonquantifiable criteria well
It is responsive to the preference scale of the decision maker
Requires only a priori preference articulation at a local level

Weakness: Large set of a priori weights and thresholds (ELECTRE II)
Some concepts and quantification procedures may not be *appealing to* the decision maker
The preference graphs become complicated and difficult to interpret for larger numbers of alternatives

Readings: (Tabucanon, 1988)

Parametric Approach: This technique uses mathematical or heuristic methods to eliminate several of a large amount of alternative solutions.

Strength: Doesn't require decision maker to articulate preference information
Decision Maker evaluates only a subset of satisfactory solutions

Weakness: May be time consuming if many efficient solutions are generated

Readings: (Tabucanon, 1988)

De Novo Programming: This technique is discussed in detail by Zeleney (Zeleney, 1976, 1982, 1986). He proposes the design of an optimum system as opposed to optimizing a given system. It uses a systems approach to evaluate alternatives besides those that already exist.

Strength: Fully uses resources, no waste or slack
Uses a budget constraint as an upper limit of activity
Achieves a high optimum in cases of fixed budgets
Expresses resource infeasiblity in monetary terms
No need to reevaluate for impacts of marginal changes in individual resources

Weakness: Not effective when decision maker does not want to design a new optimal system

Readings: (Tabucanon, 1988)

Graphic Techniques: These are visually interactive models that symbolically depict expected outcomes of each alternative relative to each attribute.

Strength: Intuitive by design
Present much information quickly
It can incorporate economic models
Presents a holistic view of the problem

Weakness: Analysts may agree on some criteria like measures effectiveness, but disagree on axis and scale for output and output interpretation
May require large amounts of time for model formulation and display

Readings: (Cook and Sieford, 1982; Canada and Sullivan, 1989; Kasanen, Ostermark, and Zeleney, 1988; Belton and Vickers, 1988; Keeney and Raiffa, 1976; Graves and Ringuest, 1991; Liberatore and Titus, 1983; Jordan, 1992)

Analytical Hierarchy Process (AHP): A procedure that ranks alternatives by pairwise comparison with respect to a higher level goal or criterion.

Strength: Partitions large problems into smaller parts
Detailed procedure to check consistency of decision makers performance
Easily incorporates tangible and intangible criteria
Does not require numerical data

Weakness: Pairwise comparisons can become ambiguous
Pairwise comparisons can become tedious
Excessively large numbers of pairwise comparisons may be required by reasonably sized problems

Readings: (Saaty, 1980, 1982; Bard, 1986; Zahedi, 1986; Vargas, 1990; Boucher and MacStravic, 1991; Battin and Bender, 1992; Jordan, 1992)

B.8 Multiattribute Utility Theory (MAUT)

This technique uses advanced mathematics with economic manipulation to evaluate alternatives against multiple criteria. Zeleney sums up the process as follows:

> ***"Multiattribute utility theory arises from the classical precepts of perfect rationality, utility or profit maximization, and predictability of aggregate phenomena. MAUT is prescriptive, concerned with the choice among prespecified alternatives according to the principle of Maximization of subjective expected utility." (Zeleney, 1982:437)***

The process arrives at an optimum course to achieve the stated goal. It can be characterized by the following five steps:

1) Determine the goal, objectives, criteria, and alternatives

2) Determine the preference of each component

3) Assign quantified values to each attribute

4) Determine a value function that is the sum of the attribute values of each alternative

5) Perform a tradeoff by deciding how much of one objective to give up to improve another objective

Strength: Works well with qualitative and quantitative data

Weakness: Requires a competent analyst
Requires reasonably accurate numerical data
Managers may not understand how qualitative data is quantified
Highly subjective
No sensitivity analysis means
Difficult to arrive at a set of assumptions that simplify the MAUT function
Assumes every decision maker is qualified to evaluate every attribute

Readings: (Keeney and Raiffa, 1976; Madey and Dean, 1885; Bouyssou, 1988; Canada and Sullivan, 1989)

Appendix C: Lateral Airfoil Design Detail

C.1 Introduction

This appendix introduces a typical lateral airfoil design for an aerospace vehicle. The narrative assumes a basic understanding of helicopter design. However, the details discussed include elementary concepts only. The format focuses on aerodynamic forces, flight controls, high speed flight, autorotation, and munitions storage.

C.2 Forces

The aerodynamic forces acting upon this new type of aerospace vehicle are identical to those acting upon all aircraft. A discussion of these forces is elementary. However, it facilitates a better understanding of the design as a whole.

During flight in a no-wind condition, the lift force acts vertically upward, the weight force acts vertically downward, the thrust force acts horizontal to the longitudinal axis toward the nose of the design, and drag acts horizontal to the longitudinal axis toward the tail of the design. This is consistent with conventional aircraft designs. As lift exceeds weight, the design climbs; if lift is less than weight, the design descends. If thrust exceeds drag, the design speeds up; if thrust is less than drag, it slows down.

A noticeable disparity with conventional aircraft becomes evident with lateral movements. In sideways flight, the lift vector resolves into two components - lift acting vertically upward, and lift acting perpendicular to the longitudinal axis. The upward lift component must exactly offset the weight; otherwise, vertical movements occur. Also, as the sideways component of lift increases the design moves in that direction. If the sideways lift component becomes less than the sideways drag, the aerospace vehicle slows its sideways flight.

Reversing the thrust allows the vehicle to backup in flight. Thrust derives from two sources. The first, and most conventional, is the engine exhaust. A secondary source of thrust is the lateral airfoil exhaust itself, which is analogous to and treated like bypass air from a turbo-fan engine. Please note Figure 5, an artist conception of the aerospace vehicle in flight.

C.3 Flight Controls

The typical cockpit flight controls parallel those of the helicopters. Further, pilot inputs at the controls yield comparable results. The similarity ends here as many differences exist in the way the aircraft interprets the control inputs. A typical mechanical linkage drawing showing the pitch, yaw and collective cams is given in Figure 55. Other methods of effecting control inputs are just as acceptable as mechanical linkages and perhaps preferable. They include hydraulic, pneumatic, fly-by-wire and fly-by-light.

The cockpit flight controls include the cyclic, collective and rudder pedals. As in the helicopter, the cyclic controls pitch and roll; movement about the vertical axis or yaw is controlled by the rudder pedals; and the collective controls movement along the vertical axis.

Moving the cyclic to the right or left effects roll or movement around the longitudinal axis. Roll is a complex operation accomplished by increasing the RPM, or torque, on one lateral airfoil system (LAS) while decreasing the RPM on the other LAS. Since the LAS with the increased RPM will produce greater lift, a compensation in individual blade pitch must be made. A converse adjustment in the blade pitch of the slower moving LAS may be made as well.

Movement about the lateral axis produces a nose-up or nose-down attitude. The change is effected by moving the cyclic pitch control fore and aft. Typically, a forward movement of the cyclic produces a nose-down pitch. Remembering the effects of gyroscopic precession and referring to Figure 56; linkage from the cyclic to the forward LAS pitch cam forces increased pitch of the blades at "A," while those at "C" decrease pitch. This action pulls the nose down. Simultaneous to this action, linkage connected to the aft LAS pitch cam causes the blades at "E" to increase pitch while those at "G" decrease pitch. This action pulls the aft of the design up. The combined effects of these complex interactions forces pitch about the lateral axis.

The collective pitch control varies the vertical lift produced by the twin-component lateral airfoil system (TCLAS). The TCLAS is simply two LAS's located one behind the other. Linkage from the collective to the collective lift cam increases or decreases the blade pitch at "A," "C," "E," and "G." Raising the collective pitch control increases the pitch of the blades near "C" and "E" while decreasing the blade pitch near "A" and "G." Lowering the collective forces an equal, but opposite action.

Many factors determine the amount of lift available for operation. Generally, the pilot has control over two of these. One is pitch angle of the individual LAS blades; the other is RPM of the TCLAS. Control of the pitch angle of the blade during its revolution around the longitudinal axis lets the pilot establish the flight characteristics of the design. Manipulation of the throttle (located on the end of the collective) produces a constant engine RPM despite the increased or decrease in blade pitch. Furthermore, synchronization of the throttle and the collective pitch control increases the power available with increased blade pitch and produces a greater load on the engine. Also, the engine power decreases with a decrease in pitch of the blades.

Movement about the vertical axis produces yaw; a nose swing to the right or left. The directional control pedals (rudder pedals) control this movement. The pedals link to the yaw cam. The yaw cam controls the blade pitch at "B," "D," "F," and "H." If the left pedal is pushed, the yaw cam of the forward LAS will cause the blades near "D" to increase pitch, while the blades near "B" decrease pitch. The pitch increases on one side combined with the pitch decrease on the other side pulls the nose of the design to the left. Simultaneous to this action, the rear LAS yaw cam will cause the blade pitch to increase at "H" and decrease at "F." The aft of the design pulls to the right. The combined effect of these actions produces yaw.

C.4 High Speed Flight

When hovering in still air the relative wind remains parallel with the chord line of the TCLAS blades. However, during forward flight at increasingly higher speeds the relative wind shifts from parallel to the chord line to perpendicular to the chord line of all the TCLAS blades. The resultant of this condition is a blade stall. Therefore, aerospace vehicles operating at consistently relative high forward velocities have blades that are twisted as shown in Figure 57. For increasingly higher forward speeds the TCLAS blade pitch completely flattens and more conventional control surfaces provide aircraft control.

C.5 Autorotation

Autorotation is the term used when the TCLAS is driven by the action of the relative wind as opposed to the engine. The transmission, or power train, disengages automatically from the TCLAS when the engine stops, allowing the TCLAS to revolve freely around the longitudinal axis. Autorotation technique and theory remain identical to that of the helicopter.

C.6 Munitions

Conventional winged surfaces, sponson's or a rotary type launcher (see Figure 56) provides attachment points for munitions or pods. A rotary launcher simplifies easy access by ground crews for installation of munitions. As they are attached, the rotary launcher advances around the aerospace vehicle allowing the ground crew to attach the next munition or pod from the same ground location.

C.7 Conclusion

This concludes a brief description of the twin-component lateral airfoil system and its application to an aerospace vehicle. Derivatives of this design could provide novel gas turbine engines that are more easily adapted to high Mach flight conditions, as well as novel seagoing vessels propelled, supported and controlled in the water with the same structural members. This text and referenced drawings, while not totally accurate nor detailed enough to meet engineering specifications, serves as a catalyst for further research into the subject.

Appendix D: R&D Project Selection Survey Instrument

D.1 Cover Letter

DEPARTMENT OF THE AIR FORCE
WRIGHT LABORATORY (AFMC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

0 2 JUN 1993

FROM: WL/CC Bldg 45
2130 Eighth St Ste 11
Wright-Patterson AFB OH 45433-7552

SUBJ: R&D Project Selection Survey

TO: See Distribution

1. I'm requesting your participation in a survey. The attached survey instrument investigates R&D project selection and resource allocation at Wright Laboratory. Publication of the discrete and aggregate R&D comparison methodology used at Wright Laboratory may serve as a model for other laboratories inside and outside the USAF.

2. This Air Force Institute of Technology research measures your opinions concerning the utility of various formal decision making techniques. Besides the survey, some of you may be asked to participate in a short interview. I have been assured of the confidentiality of your responses in both cases.

3. If you have any questions, or if you would like to obtain a copy of the research results, please contact the researcher through the following address:

Department of the Air Force
AFIT/LAA (Capt James Barger)
2950 P Street
Wright-Patterson AFB OH 45433-7765
Office Phone: (513) 255-8989

DAVID A. HERRELKO
Colonel, USAF
Commander

1 Atch
R&D Project Selection Survey

D.2 Survey

R&D Project Selection Survey

Suspense: Please accomplish before 20 June 1993.

Time: The survey takes approximately 8 minutes to complete.

Purpose: The survey investigates the R&D project selection and resource allocation process at Wright Laboratory. Several formal techniques have been developed or proposed in literature to help R&D managers in making project selection decisions. This survey measures your opinions concerning the utility of these techniques and characterizes the resource allocation process. Publication of Wright Laboratory's discrete and aggregate comparison methodology is important since it may serve as a model for other institutions within and without the USAF.

A formal project selection technique is any model or algorithm used to systematically assign values to individual R&D projects or groups of projects. Formal project selection techniques can be grouped into the following categories:
1) subjective methods; 2) economic techniques; 3) risk analysis techniques; and
4) mathematical programming models. A partial list of project selection techniques appears in questions 1 through 15 of this survey.

Confidentiality: Your responses to the survey will be strictly confidential.

Survey Responses: This is a voluntary exercise, however, you are an important part of this survey. Your response is crucial to the project's success.

None of the survey questions require you to look up information. Only your opinions are sought. You should mark your response quickly after carefully reading the questions. If you would like to make any comments, please feel free to mark them directly on the survey.

After completing this survey, please place it in the return envelope provided and mail it promptly. If you have any questions or you would like to obtain a copy of the results, please contact me at the following address:

Department of the Air Force
AFIT/LAA (Capt James Barger)
2950 P Street
Wright-Patterson AFB, OH 45433-7765
Office Phone: (513)-255-8989

THANK YOU FOR YOUR TIME AND COOPERATION.

Part I

The following is a list of formal project selection techniques. If you are familiar with the technique, please place an "X" in the appropriate column. If you also use the technique regularly in your project selection process, please mark the appropriate column. If you are not familiar with the technique, please do not mark either column.

Technique	Familiar With	Use Regularly
1. Sort	______	______
2. Checklists	______	______
3. Scoring Models	______	______
4. Delphi	______	______
5. Cost/Benefit Ratios	______	______
6. Payback Period	______	______
7. Net Present Value/ Internal Rate of Return	______	______
8. Portfolio Models	______	______
9. Risk Analysis (Monte Carlo Simulation)	______	______
10. Decision Analysis/ Decision Trees	______	______
11. Linear Programming	______	______
12. Integer Programming	______	______
13. Nonlinear Programming	______	______
14. Dynamic Programming	______	______
15. Goal Programming	______	______
16. Others? Please list below.		

For the following questions, please indicate the expression that most closely matches your opinion. The answers are categorized using a scale from one to seven. The use of the term "formal project selection techniques" refers to techniques such as those listed in questions 1 through 16.

17. How would you assess the amount of influence that you have on your organization's R&D project selection and resource allocation process?

Very Strong Influence		Strong Influence		Some Influence		Little Influence		No Influence

1	2	3	4	5	6	7

18. How would you assess the adequacy of the manner in which your division reviews and evaluates potential R&D proiects?

Could be Improved a Great Deal	Could be Improved Somewhat	Uncertain	Probably Could Not be Improved	Could Not be Improved

1	2	3	4	5	6	7

19. How would you assess the potential worth, to you personally, of a technique which would be designed to assist you in measuring the comparative value of potential R&D projects?

Extremely Bene-ficial	Somewhat Bene-ficial	No Benefit or Uncertain	Somewhat Detri-mental	Extremely Detri-mental

1	2	3	4	5	6	7

20. How would you assess the potential worth, to those people with whom you work, of a technique which would be designed to assist them in measuring the comparative value of potential R&D projects?

Extremely Beneficial		Somewhat Beneficial	No Benefit or Uncertain		Somewhat Detrimental	Extremely Detrimental
1	2	3	4	5	6	7

21. How important, to you personally, would you consider a decision to use a formal project selection technique on all your R&D projects?

Very Important to you		Somewhat Important to you	Neither Important nor Unimportant		Somewhat Unimportant to you	Very Unimportant to you
1	2	3	4	5	6	7

22. If such a decision were to be made what would you recommend?

Definitely Should Use		Probably Should Use	Uncertain		Probably Should Not Use	Definitely Should Not Use
1	2	3	4	5	6	7

23. How important, to you personally, would you consider a decision to use a formal project selection technique on at least 50 percent of your R&D projects?

Very Important to you		Somewhat Important to you	Neither Important nor Unimportant		Somewhat Unimportant to you	Very Unimportant to you
1	2	3	4	5	6	7

24. If such a decision were to be made what would you recommend?

Definitely Should Use		Probably Should Use	Uncertain		Probably Should Not Use	Definitely Should Not Use
1	2	3	4	5	6	7

25. Do you feel it is likely that a formal project selection technique could be developed which would be useful to you during your project selection and resource allocation process?

Very Likely		Likely	Uncertain		Unlikely	Very Unlikely
1	2	3	4	5	6	7

26. To what extent do you feel "pressure" from <u>outside</u> Wright Laboratory to quantitatively justify your R&D expenditures?

Extreme Pressure		Significant Pressure	Some Pressure		Little Pressure	No Pressure
1	2	3	4	5	6	7

27. To what extent do you feel "pressure" from <u>within</u> Wright Laboratory to quantitatively justify your R&D expenditures?

Extreme Pressure		Significant Pressure	Some Pressure		Little Pressure	No Pressure
1	2	3	4	5	6	7

28. In the space below, please describe any positive or negative experiences you've had when using, or attempting to use, a formal project selection technique.

Part II

Each item in this portion of the survey consists of a statement with which you are asked to agree or disagree. Using the scale shown below, please indicate the extent to which you agree or disagree with each statement. Place a number which corresponds to your opinion in the space provided. Please indicate your opinion even though you may not feel strongly about the statement, or do not feel well informed. Only your initial perceptions are sought. Please try to avoid marking a "3" (Cannot agree or disagree) if possible.

Strongly Agree	Tend to Agree	Can't Agree or Disagree	Tend to Disagree	Strongly Disagree
1	2	3	4	5

Using the scale shown above, please place a number in the space provided which corresponds to your opinion about each statement.

______ 29. I am, in general, very satisfied with the manner in which projects and tasks are reviewed and evaluated in our division.

______ 30. The need for a formal project selection technique is not great relative to other changes that could be made in our laboratory's project review and budget allocation process.

______ 31. My assessment of particular projects or tasks is not likely to change as a result of using a formal project selection technique.

______ 32. A formal project selection technique would help to make my budget recommendations more compatible with those of my superiors.

______ 33. A formal project selection technique would help to make my budget recommendations more compatible with those of my research staff.

______ 34. A formal project selection technique is likely to increase the confidence I have in my budget recommendations.

Strongly Agree	Tend to Agree	Can't Agree or Disagree	Tend to Disagree	Strongly Disagree
1	2	3	4	5

Using the scale shown above, please place a number in the space provided which corresponds to your opinion about each statement.

_______ 35. A formal project selection technique will affect the type of information exchanged when I review and evaluate the projects and tasks in my division/branch.

_______ 36. A formal project selection technique will affect the amount of information exchanged when I review and evaluate thc projects and tasks in my division/branch.

_______ 37. The manner in which we review and evaluate projects and tasks in our division does not lend itself to the use of a formal project selection technique.

_______ 38. Formal project selection techniques are, in general, difficult to use and understand.

_______ 39. The information generated by a formal project selection technique cannot be easily communicated to others.

_______ 40. My use of a formal project selection technique is likely to enhance the worth of my budget recommendations.

_______ 41. My use of a formal project selection technique is likely to be considered, by my immediate superiors, as having enhanced the worth of my budget recommendations.

_______ 42. My use of a formal project selection technique is likely to be considered, by my research staff, as having enhanced the worth of my budget recommendations.

_______ 43. More relevant information is likely to be exchanged in my division/branch if I use a formal project selection technique.

Strongly Agree	Tend to Agree	Can't Agree or Disagree	Tend to Disagree	Strongly Disagree
1	2	3	4	5

Using the scale shown above, please place a number in the space provided which corresponds to your opinion about each statement.

______ 44. A formal project selection technique is likely to help identify critical or sensitive aspects of my projects or tasks.

______ 45. My use of a formal project selection technique is likely to increase the overall effectiveness of reviewing and evaluating our division's projects and tasks.

______ 46. The output data that would be generated by a formal project selection technique could not adequately meet my need for such data.

______ 47. I have some reservation about the way in which formal project selection techniques combine or manipulate the input data.

______ 48. I would find it extremely difficult to obtain the input data necessary to use a formal project selection technique.

______ 49. The need for a formal project selection technique is very much increased when funds are scarce.

______ 50. I would recommend that a formal project selection technique be used on all of the projects or tasks in my division.

______ 51. I would recommend that a formal project selection technique be used on at least 50 percent of the projects or tasks in my division.

______ 52. The process by which most formal project selection techniques generate their output data could easily be explained to my colleagues.

Strongly Agree	Tend to Agree	Can't Agree or Disagree	Tend to Disagree	Strongly Disagree
1	2	3	4	5

Using the scale shown above, please place a number in the space provided which corresponds to your opinion about each statement.

______ 53. I personally feel that R&D project selection decisions which are based on experience and expertise will yield better results than decisions made with the use of a formal project selection technique.

______ 54. The output data generated by a formal project selection technique could be easily interpreted by laboratory decision makers.

______ 55. It is likely that a formal project selection technique will provide common outputs that could be easily understood by all laboratory decision makers.

______ 56. The mathematics involved in most formal project selection techniques are more complicated than is necessary for our project selection process.

______ 57. The input data for most project selection techniques is difficult to generate due to the uncertainties associated with technological developments.

______ 58. When I make R&D project selection decislons, I prefer to use a structured, quantifiable process.

Part III

59. What is your gender? (Circle one) A) Male B) Female

60. What is your age? (Circle one)

A) 20-25	B) 26-30	C) 31-35
D) 36-40	E) 41-45	F) 46-50
G) 51-55	H) 56 +	

61. Please print your military rank or civilian grade. ______

62. Which Wright Laboratory organization are you associated with? (Circle one)

A) Command Section
B) Operations & Support Directorate
C) Avionics Directorate
D) Solid State Electronics Directorate
E) Flight Dynamics Directorate
F) Assistant Director, Financial Mgmt and Comptroller
G) Materials Directorate
H) Armament Directorate
I) Manufacturing Technology Directorate
J) R&D Contracting Division
K) Aero Propulsion & Power Directorate
L) Plans & Programs Directorate
M) Other

63. Which organizational level best describes your position? (circle one)

A) Directorate
B) Division
C) Branch
D) Section
E) Other

64. What is the highest educational level you have obtained?
(Circle one)

A) High School Diploma
B) Associate's Degree
C) Bachelor's Degree
D) Master's Degree
E) Ph.D.
F) Other

65. What were your major fields of study in the degrees you've obtained?

A) Associate's Degree ____________________
B) Bachelor's Degree ____________________
C) Master's Degree ____________________
D) Ph.D. ____________________

66. Have you ever taken a course, or attended a seminar in either management science or operations research techniques?
(Circle one)

A) Yes B) No

67. Would you be willing to attend a course or seminar on formal R&D project selection techniques? (Circle one)

A) Yes B) No

68. Have you ever taken a course or seminar in R&D or laboratory management? (Circle one)

A) Yes B) No

69. What is the approximate size of the budget you are responsible for?

$________________.

70. What is your estimate of the percentage of your division's budget dedicated to in-house research versus contracted research?

In-house %_____ Contracted %_______ (Total 100%).

71. What is your estimate of the percentage of your budget that is dedicated to discretionary research efforts which are chosen by your division for their potential value to future Air Force weapons systems, as opposed to research efforts which are specifically requested by an Air Force system program office (SPO) or another outside organization to support a particular weapons system?

Discretionary research chosen by you or your division %________

Research specifically requested by a SPO or outside organization %________ (Total 100%)

THE END

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS SURVEY
YOUR COOPERATION IS GREATLY APPRECIATED

Appendix E: Survey Data Base

The survey data was transferred to optical scan sheets for input into AFIT's computer. The following printout shows the survey results as alphanumeric characters. Please refer to Appendix D for survey questions. However, in an effort to maintain the survey members confidentiality, the column format and it's reference survey question have been deleted. This information is available for researchers upon request pending AFIT approval.

```
00002052DAAAADDDADADDDDDDCBCBCBBDFDNDBCCCBBBBCDBBCCBCDBCBDCBBBBCCBAFDEIHEBAACBE
00002052
00002053DDDDDDDDDDDDDDDDBCBCCCCCBGGNBBCEECCCDCDCCCCBCCCDDCCCBCCCCBAEDK KEBABBBB
00002053
00002054DDDDDDDDDDDDDDDD                                         AFELDLDBBBBAA
00002054
00002140DDDDDDDDDDDDDDDDDDBDBBCBBCECNDADCCBBBCCBCEDBBBDBACEBCACCBACABGCNDCBBADBG
00002140
00002139DAAADDDDAADDDADDAEDCEEFDFGFAAABDDEBDCDCEDEDDEDEACEEBABCBADAHME DD  ABEC
00002139
00002138DCADCCDDDADDDDDDEBDDGGGDGAAACABDDEBBDBDDCCDBDCBBDEEEAEECBDAG I DDB ACAE
00002138
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Appendix F: Interview Guide/Response Sheet

Figures 55-57 are reproductions from sections of a large blue print that was shown to the participants during the 5-7 minute lateral airfoil overview. Appendix C details the depth of information revealed during the "brain storming" session that followed. Participant determinant attributes were recorded on the margin at the bottom of the first page.

A. You are given an engineering development cost estimate of **$210 million** for a proposed Lateral Airfoil research project.

1. Mark your opinion of the utility of the cost estimate in a decision to expedite, shelve or abort the proposed research project.

Low Utility High Utility

2. Which of the following positions would you champion? (select one)

a. Support the project
b. Table the project until some later date
c. Oppose the project

3. List any other determinant attributes used and your opinion of their utility.

1. ____________________.

Low Utility High Utility

2. ______________________________.

Low Utility High Utility

3. ______________________________.

Low Utility High Utility

4. ______________________________.

Low Utility High Utility

2. ______________________________.

Low Utility High Utility

3. ______________________________.

Low Utility High Utility

4. ______________________________.

Low Utility High Utility

Interview Survey Form

B. Three or four letter office symbol ______________

C. Please mark your opinion of the utility of the following decision making attributes using the line mark scales.

1. **Time Period:** the estimated project completion time

Low Utility High Utility

2. **Resource Availability:** availability of personnel, equipment, or facilities

Low Utility High Utility

3. **Technical Merit:** characterized as new or better capabilities

Low Utility High Utility

4. **Likelihood of Success:** probability of achieving technical success within time constraints

Low Utility High Utility

5. **Air Force Need:** the degree the Air Force has articulated a need

Low Utility High Utility

6. **Cost/Benefit Ratio:**

Low Utility High Utility

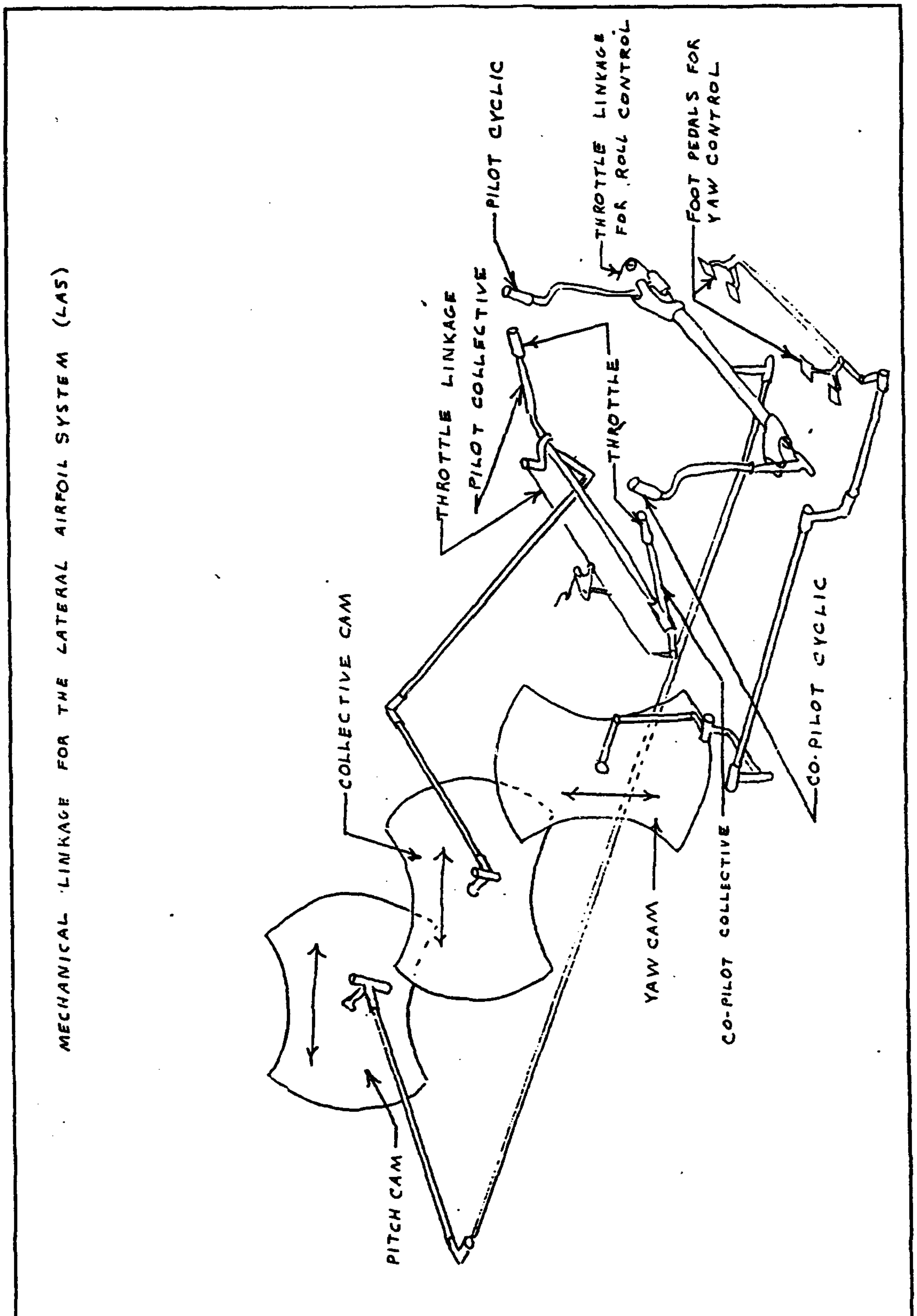

Figure 55. **Mechanical Linkages for the Lateral Airfoil System**

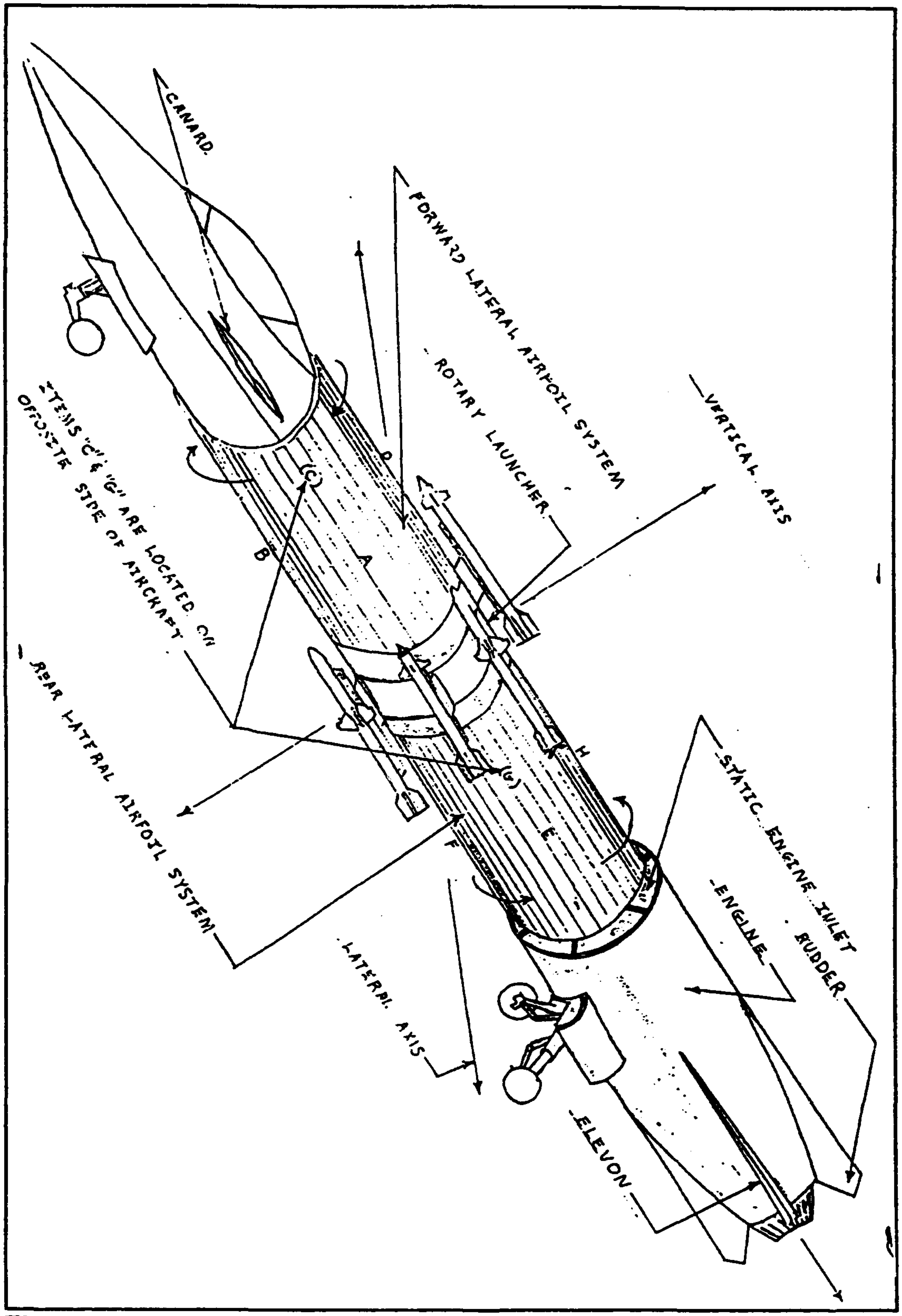

Figure 56. **Aerospace Vehicle Detail Drawing**

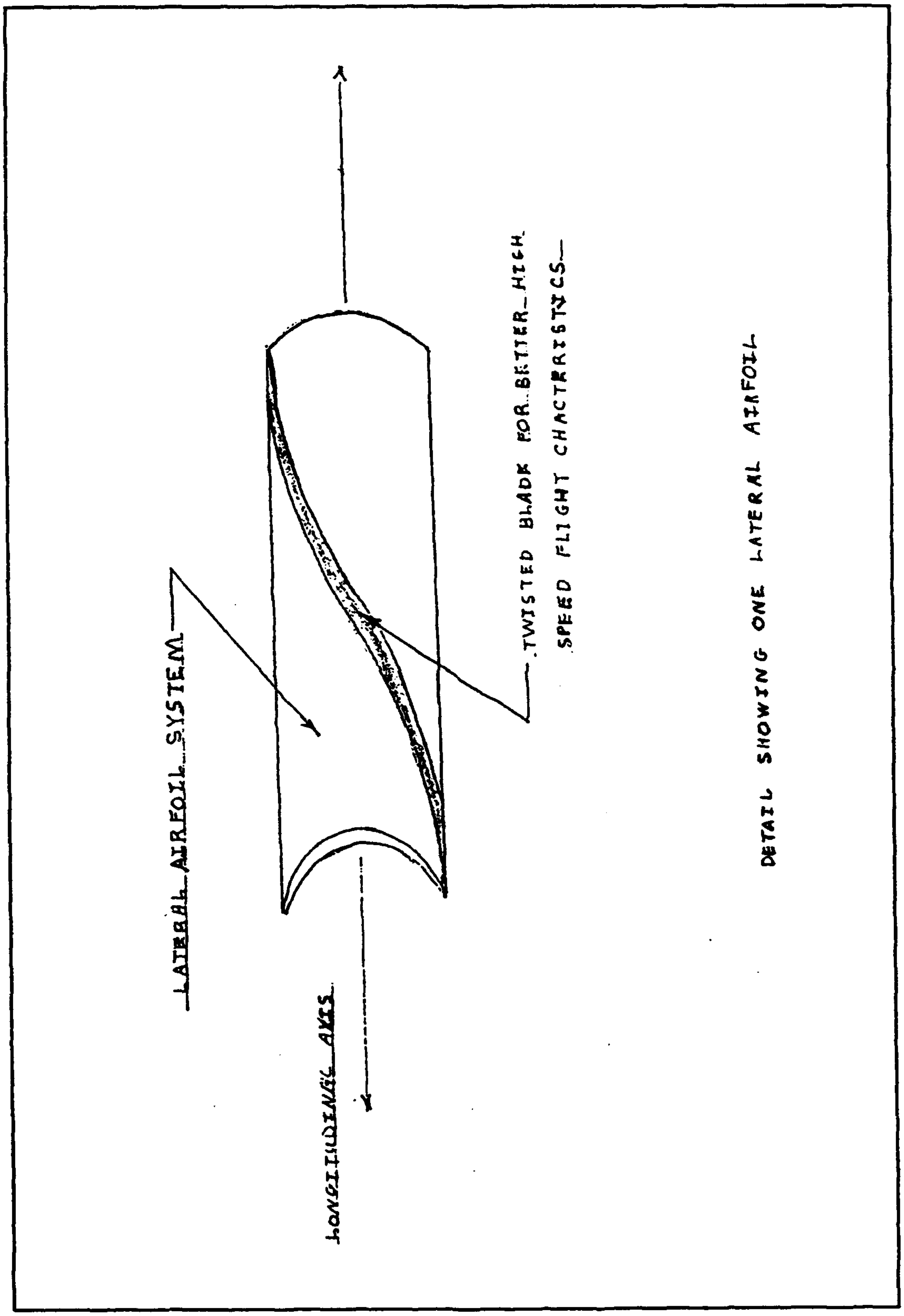

Figure 57. **High Speed Flight Airfoil**

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Vita

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13. ABSTRACT (Maximum 200 words) This research accomplished three major tasks. First it examined familiarity and usage rates for fifteen published R&D project selection methods in the context of a larger general issue, the Air Force's ability to develop and exploit technology. Wright Laboratory served as the focus for the research effort and displayed a greater tendency to use formal methods in 1993 than was shown in prior research. The laboratory's overall preference for simpler models like Checklist, Scoring, and Sorting led to a recommendation that authors familiar with the other techniques communicate them in engineering and management vernacular.

Secondly, the study introduced a technological paradigm, lateral airfoils. The methodology employed one of three new lateral airfoil applications and used it to meet the third initiative.

Finally, the study used a "placebo" lateral airfoil research project to gauge Wright Laboratory's decision making process. The study revealed thirty discrete criteria and successfully reduced these to seven determinant attributes indicative of overall laboratory support for applied research efforts.

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